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BEHIND THE DIAL

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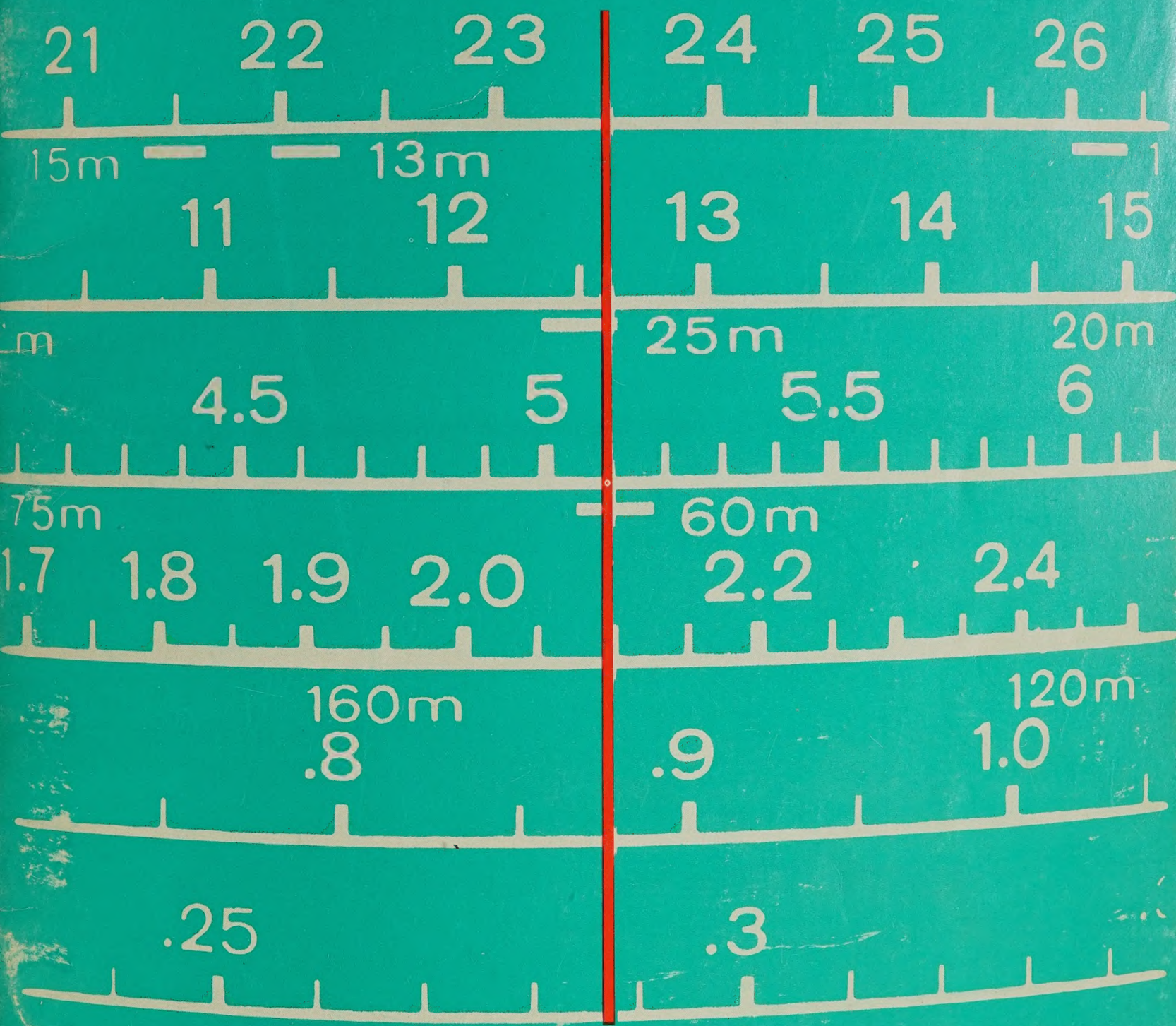

By Bob Grove

A 73 PRODUCT

BEHIND THE DIAL

By Bob Grove

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Prologue

In the early days of radio, listeners had to tune their receivers over a considerable range to intercept broadcast stations, not to mention much rarer two-way communications. Now, there is growing evidence that the increase in radio-wave saturation of our environment by transmitting stations may pose a serious health hazard. The Citizens Radio Service alone comprises millions of transmitters in the United States.

This explosive growth in the radio spectrum has occurred in little more than a half century.

The land mobile service began in 1921, when the Detroit Police Department first pioneered mobile radio using a five Watt AM transmitter built by Western Electric.

By the 1930's and 40's many home-entertainment radios were capable of tuning the lower portion of the familiar shortwave spectrum. Police broadcasts dotted the 2 Megahertz portion of the dial, while a few adventurous hams could be found higher in frequency. Voice communications were nearly always in the AM mode, readily copied by bargain-basement radios.

By 1948 there were 83,000 licensed land-mobile transmitters licensed in the United States; today the users number over five million . . . increasing at a rate of some 20% each year!* Crowding of the radio spectrum has created an acute and critical shortage of air space, driving users ever higher in frequency. Communication between stations is rarely accomplished without interference from other users of the spectrum; consequently, a new technology has grown. Single-sideband techniques have effectively doubled, or even trebled, the available channel space by narrowing the width of transmitted radiotelephone signals. Narrow-band FM transmission and reception have also helped increase the number of available channels formerly occupied by wideband stations.

It has been estimated that the Citizens Radio Service alone comprises an additional 20 million users.

The number of listeners has grown proportionately; the excitement of listening to a military maneuver, the intrigue of intercepting government communications, the drama of a police emergency . . . all contribute to the allure of an ever-growing hobby. Government and commercial monitoring installations are also increasing in number.

An introduction into this wonderful world of listening does not have to be unrealistically expensive; many high-quality surplus receivers are available from a ready marketplace. Used commercial equipment is advertised in an array of radio publications at attractive prices. A casual glance through the classified sections of these magazines will provide a list of sources. If in doubt, consult the advice of a licensed radio ham; invariably, these public-minded hobbyists are happy to help newcomers in any aspect of radio and electronics, and will try to provide them with a number of possible solutions to questions which may arise. For the advanced listener, communications journals and electronics directories carry listings of equipment manufacturers.

The author of this book presupposes the reader to have a basic understanding of electronics; in case of further questions, references to publications and equipment sources are included frequently to encourage the reader's inquiry.

Whether your interest in monitoring communications is professional or recreational, this book will prove to be an invaluable guide in designing and using a receiving installation for the first 1000 Megahertz of the radio spectrum.

DEDICATION

This book is dedicated to those alert individuals who believe that freedom to be aware preserves democracy . . . with special thanks to Philip Accardi, whose engineering expertise provided an invaluable critique in the formulation of this work.

EDITOR'S COMMENTARY

It is with great pleasure that we welcome Bob Grove to the ever growing family of 73 authors. Bob has been highly successful and with the publication of this, his latest book, I'm sure his success will grow to even greater heights. He is surely an expert in the field of communications and the radio frequency spectrum.

With the publication of this book it is hoped that many people will be introduced to the exciting field of shortwave listening, or as it should be called Communications Monitoring.

Rich Force

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Chapter 1

The Electromagnetic Spectrum: A Review

The discovery that the standing waves produced when alternating current flows through a conductor will propagate a field which has both electric and magnetic properties, ushered in the radio age.

A single pulse of current will move through our atmosphere and the vacuum of space at the speed of light: nearly 300 million meters per second (over 186,000 miles)! The free-space impedance to this wave is 377 Ohms. The number of current reversals per second is called frequency; naturally, as the frequency increases, the distance between each successive wave (wavelength) decreases. This universal relationship may be expressed by the equation $f\lambda = c$, where f is frequency in Hertz, λ is wavelength in meters, and c is the velocity of the wave (300 million meters per second). Thus, the wavelength of a one-megahertz broadcast station is 300 meters.

$$\left(\lambda = \frac{3 \times 10^8 \text{ m/s}}{1 \times 10^6}\right.$$

$$= 300 \text{ meters}).$$

Many radiant phenomena have frequency and wavelength (although not all are electromagnetic): sound, heat, light, nuclear radiation, x-rays, and cosmic rays. Since these are arranged in order of increasing frequency (shortening wavelength), it is possible to assign a position for the radio portion of this continuous spectrum; it would be placed between sound (which is acoustic rather than electromagnetic) and heat (infrared light).

Officially, the Federal Communications Commission (FCC) and the International Telecommunications Union (ITU) assign the frequency range 10 kilohertz through 275 gigahertz (275,000 megahertz) as the allocated radio spectrum; frequencies above and below this range are unallocated, although not uncontrolled, see Fig. 1-1.

The range of frequencies most convenient and practical to monitor are those below 1000 megahertz; above VHF the shorter wavelengths begin to behave more like light. As such they are highly directional. Communications signals are sharply-beamed by focusing antennas and are more difficult to intercept than those at lower frequencies. For this reason, the remainder of this book will consider only the effective monitoring of signals below 1000 megahertz.

FREQUENCY-BAND CLASSIFICATION

Extremely Low Frequency (ELF) 30-300 Hz, Voice Frequency (VF) 300-3000 Hz, and Very Low Frequency (VLF) 3,000-30,000 Hz (3-30 kHz). Ground waves (surface waves) are very effectively propagated at these frequencies (Fig. 1-2). As the frequency increases, so do the losses in the conducting medium (earth and water); for this reason, the lowest frequencies are chosen for communications with submerged submarines.

The U.S. Navy's Seafarer Project (formerly Project Sanguine), intends to transmit 75 Hz signals to submerged submarines worldwide. Because of the wavelengths involved, transmitting antennas are several miles long. Skywave propagation is important at night at these wavelengths, but is severely attenuated during the daytime by solar effects on the ionosphere. Virtually all radio transmissions below 30 kHz are continuous wave (International Morse Code), unmodulated carriers, teletype (frequency-shift keying), and facsimile.

Low Frequency (LF) 30-300 kHz and Medium Frequency (MF) 300-3000 kHz. Although ground waves still play the dominant role in signal propagation, sky waves have increasing effectiveness. At night, sky waves reflecting from the ionosphere may provide radio coverage for thousands of miles. Just as the electrical characteristics of the ionosphere depend upon the sun, sky-wave propagation at these frequencies is subjected to daily, seasonal, and sometimes erratic changes.

Voice signals (most of which are broadcast stations) encountered in this region of the spectrum will be standard amplitude modulation (full-carrier AM). Although some military installations are equipped with LF or MF single sideband, that mode is rarely used.

High Frequency (HF) 3,000-30,000 kHz. The familiar 3-30 MHz shortwave spec-

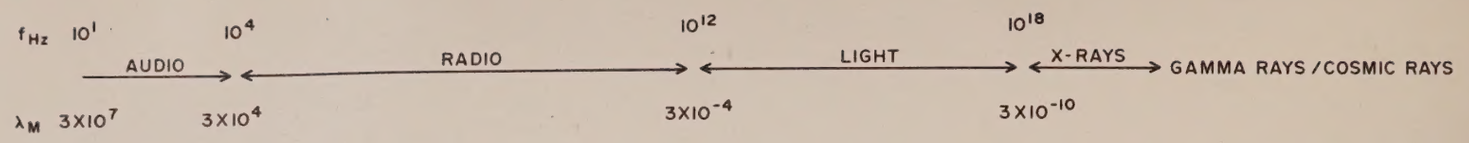

Fig. 1-1. The continuous electromagnetic spectrum, showing frequency (Hz) and wavelengths (meters).

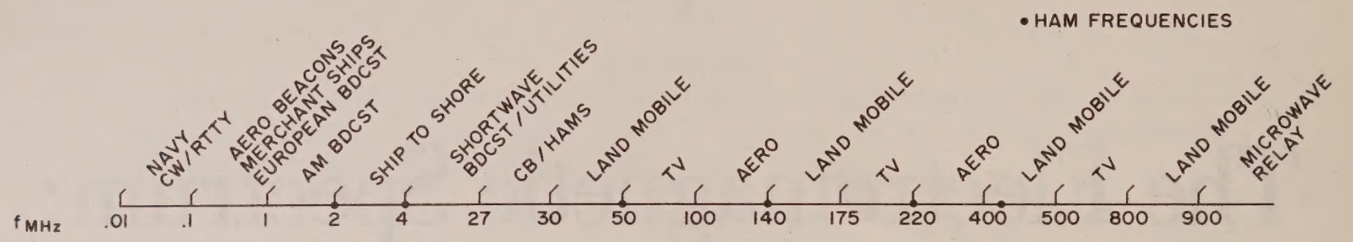

Fig. 1-2. A general view of the most familiar portion of the radio spectrum showing major users.

trum is the most active, varied, and popular region of the radio spectrum. Virtually every mode of emission (except wideband techniques) will be found here. Surface waves are rapidly attenuated; dominant propagation is by sky waves, especially for distances greater than 100 miles.

Very High Frequency (VHF) 30-300 MHz and Ultra High Frequency (UHF) 300-3000 MHz. This is the dominant region of the spectrum for portable/mobile services. Antennas are short, propagation is mostly line-of-sight (less interference from skip stations), and atmospheric disturbances are less likely to interfere with intended short-range communications. A large portion of this frequency range is occupied by commercial FM radio and television broadcasting, using wideband emission for high fidelity sound and video resolution.

Narrow-band FM is the only mode used by the public safety services scattered throughout this region (Fig. 1-3).

A more recent (although less known) classification of frequency ranges is: A Band (0-250 MHz), B Band (250-500 MHz), and C Band (500-1000 MHz).

RADIO WAVE PROPAGATION

Due to their common electromagnetic nature, radio waves and light waves share many analogous properties: polarization, refraction, transmission (conduction), absorption (filtration and attenuation), radiation, phase interference, diffraction, diffusion (mixing), and dispersion (scattering).

Any or all of these characteristics may selectively distort the free-space propagation pattern of radio waves, reducing or even enhancing the likelihood of reception.

A descriptive vocabulary has grown around these various properties and characteristics of radio waves; these will be discussed below.

Ground Wave. By definition, *ground wave* propagation is confined to those waves which stay close to the ground, and do not depend upon upper-atmospheric reflection or refraction. *Surface waves* actually stay in contact with the ground, becoming rapidly attenuated after just a few miles. Maximum distances of up to 100 miles or so are possible at MF and below. A *space wave* is the direct radiation which travels line-of-sight, bending slightly beyond the visual horizon.

Horizontal antennas are not recommended for space-wave communications below mid-HF frequencies; the ground reflects upward a large portion of the transmitted energy from simple dipoles, especially at elevations below ¼ wavelength. Even at VHF and UHF, virtually all land-mobile services utilize vertical antennas for their 10-50 mile short-range communications.

Some skip-propagation occurs at VHF, especially at the low-frequency end of that portion of the spectrum, due to ionospheric reflection.

Sky Wave Propagation. The ionosphere is an electrical zone of our upper atmosphere, varying from about 50 to 300 miles altitude (Fig. 1-4). It is produced primarily by the reaction of the ultraviolet sunlight on rarefied air molecules, causing them to become electrically charged, or "ionized." This process endows the ions with the property of reflecting or absorbing those radio waves which would normally continue out into space. The ionosphere is divided into distinct regions:

D-layer: The lowest level, present during daylight only (ion density corresponds to the elevation of the sun); reflects LF and VLF waves, absorbs MF waves, and partially absorbs HF waves.

E-layer: About 100 miles altitude; density also corresponds closely to the elevation of the sun; in the daytime it reflects HF signals back to Earth for skip distances of under 1000 miles ("short-skip" propagation); nighttime MF reflection is in excess of 100 miles.

Sporadic-E: Irregular and mostly unpredictable clouds of unusually-high ion density at the E-level. Reflective at VHF, causing unusually-long skip propagation; may occur day or night. Meteor bursts also enhance the VHF reflectivity of the lower E-layer.

F_1-layer: Above 150 miles, daylight only. Occasionally reflective of HF waves, but usually absorptive to HF waves which penetrate and return after reflection from the F_2-layer.

F_2-layer: The highest level (200-300 miles altitude), and principal HF reflector. Both height and ionization density vary daily, seasonally, and with solar activity such as sunspots and flares. Upper levels may be so densely ionized that HF radio waves are refracted (bent) as well as reflected.

Because of the reflective characteristics of the ionosphere, sky waves may skip over prospective listeners between the transmitter and the down-path of the reflected signal. If the listener is out of range for ground wave, he may not hear anything; another listener much farther away, however, may be in the fortuitous location of the returning skip, and enjoy excellent reception!

At HF and lower frequencies, virtually all communication beyond a few miles is by sky wave. Ionospheric reflection may return to the earth only a few miles

distance from the transmitter (high angle of radiation), or thousands of miles away (low angle of radiation). In the case of multi-hop propagation, radio waves may bounce back and forth between the surface of the earth and the ionosphere completely encircling the earth!

Polarization. If the oscillating electric field of a radio signal wave-front is in a vertical plane (perpendicular to the earth), we say the signal is vertically polarized; similarly, if the electric field oscillates in a plane parallel to the earth's surface, we say the signal is horizontally polarized. Each mode has its advantages and disadvantages. For ground-wave reception, it is important for the transmitting and receiving antennas to be in the same plane; matched polarization insures maximum signal interception.

Sky wave signals are generally of mixed polarization, and a choice of horizontal or vertical receiving antennas should be based upon other considerations. Horizontal antennas are generally directional. Their physical lengths at lower frequencies intercepts more signal voltage; however, they require cumbersome high-elevation supports, and generally longer transmission lines.

Simple vertical antennas are non-directional, low wave angle antennas. They are shorter than dipoles (because of practical limitations) at the lower frequencies, and cannot discriminate against direction of interfering signals. Vertical antennas are noticeably more prone to automotive ignition noise pickup at all frequencies than are horizontal antennas. On the other hand, power line noise is predominantly horizontally polarized.

Many factors must be considered for the final choice of antenna polarization; often *both* are selected, with a switching option provided at the operating position.

Radiation Angle. Although the characteristic which we call "angle of radiation" is most properly applied to transmitting antennas, reception of radio waves has an analogy. A horizontal antenna close to the ground suffers from phase cancellation if an incoming sky wave arrives out of phase with a ground reflected wave. The higher the horizontal antenna is above the reflective ground, the more dissipated is the interfering reflected wave by the time it reaches the antenna; this is a strong argument for *high* horizontal antennas.

A low angle of radiation (and reception) is recommended for all communications antennas.

Atmospheric (Tropospheric)

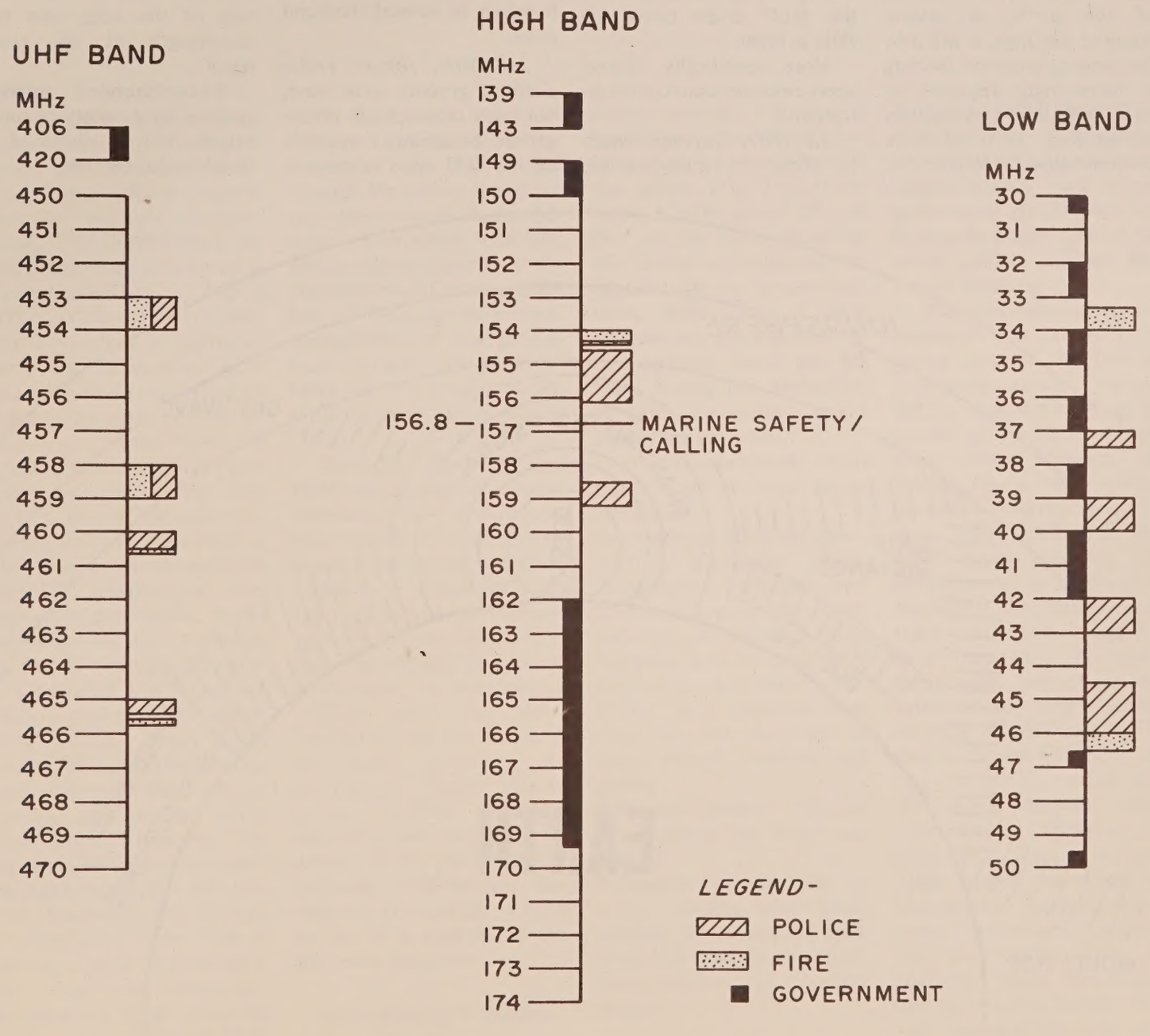

Fig. 1-3. The most active nationwide police, fire and government mobile frequency allocations.

Refraction. The bending of radio waves would be sharp if the density of our atmosphere would change abruptly; such is not the case. The higher the altitude, the thinner the air. As a result, refraction of radio waves is a gradual bending process, often following the curve of the earth's surface. This characteristic may be enhanced by *ducting*, whereby the radio waves become entrapped between two temperature-inversion layers, bouncing back and forth to be carried great distances, much as in a wave guide. Depending upon the altitude of the duct, the signal may or may not be heard: if it is just a few feet above the surface of the earth, or several hundred feet high, it will miss the antenna entirely! Ducting is increasingly apparent at VHF and UHF, especially in the tropics. It is of little concern below 30 MHz.

Maximum Usable Frequency. The MUF is the highest frequency recommended for reliable two-way communication over a specified skip-distance at a stated time of day; ionospheric propagation, signal attenuation, and atmospheric noise all contribute to establishing the MUF. It is an important consideration in long distance monitoring techniques and varies seasonally. Several amateur radio journals publish monthly propagation forecasts (i.e., *73 Magazine*).

As a general rule, 10 MHz is often arbitrarily chosen to divide the daytime/nighttime bands; frequencies higher than 10 MHz are favored during daylight hours, while the MUF drops below 10 MHz at night.

More specifically (based upon amateur radio communications):

1.8 MHz. Daytime ranges to about 25 miles or so; winter nights 2000-3000 miles.

3.5 MHz. Daytime to 200 miles; winter nights several thousand miles. Summer atmospheric lightning noise is high, covering long distances.

14-21 MHz. Rarely used for ground wave; excellent global skip, often around the clock (especially during sunspot peaks).

28 MHz. Highly sunspot-dependent, and a daylight band. Sporadic-E skip during Spring and Summer provides single-hop distances of over 1000 miles, multi-hop 2000-3000 miles.

50 MHz. 50-100 mile ground-wave coverage; summer multi-hop from several hundred to several thousand miles.

148 MHz. Almost exclusively a ground wave band, but with tropospheric propagation occasionally possible up to 1000 miles or more in the summer.

432 MHz. Ionospheric effects are virtually unknown at upper VHF and UHF; ground wave is the rule, with signal attenuation increasing with frequency.

Naturally, these basic characteristics may be interpolated for frequencies between these bands, averaging out their anticipated behavior for particular listening requirements.

Diffraction. When radio waves pass a sharply-defined obstacle, such as a hilltop or building, they propagate into the shadow zone. The degree to which this happens is dependent upon several factors, including the sharpness of the edge, and the wavelength of the radio signal.

Recommended antenna systems for a variety of applications will be discussed in detail in chapter five.

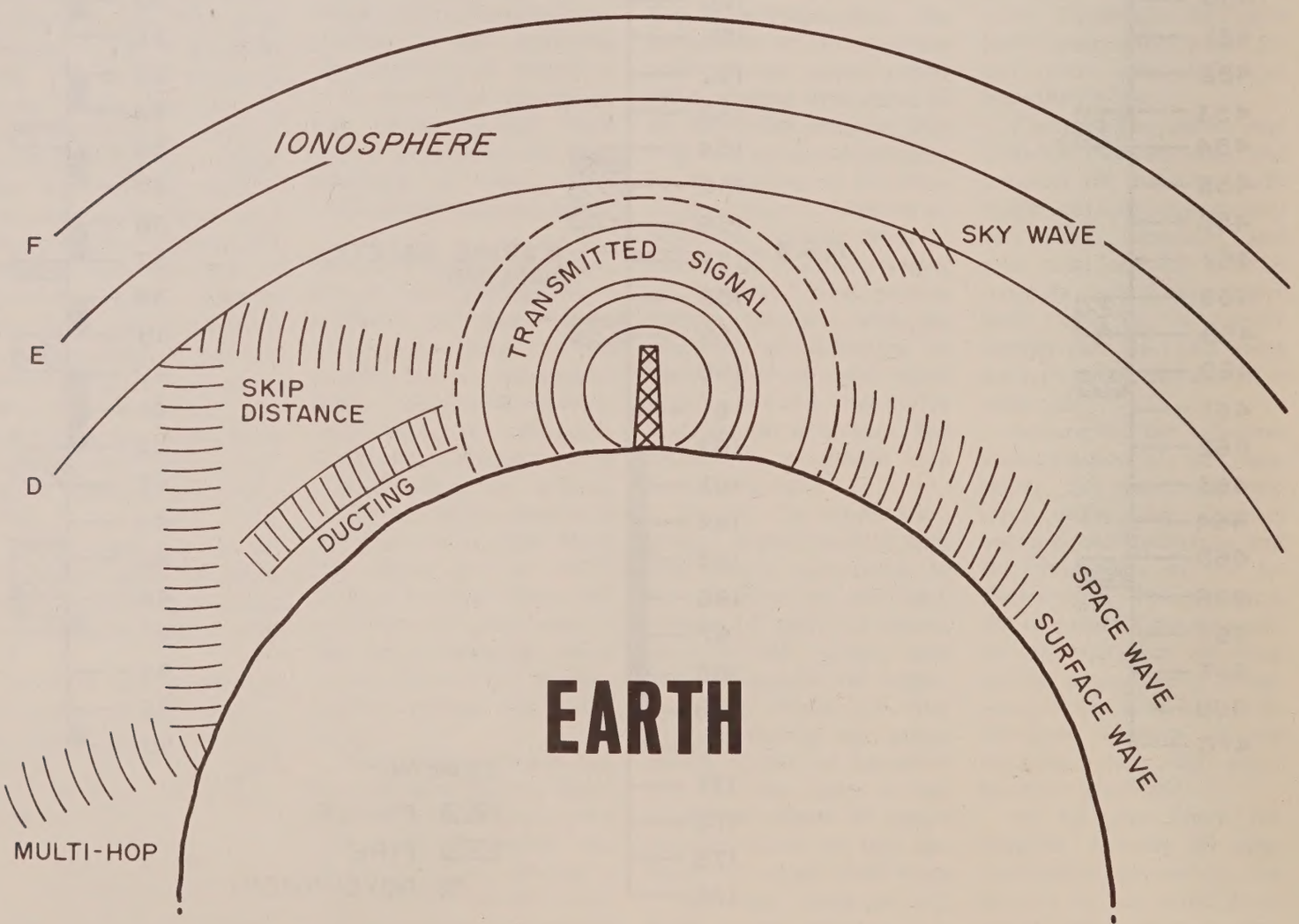

Fig. 1-4. The many paths of wave propagation.

Chapter II

Users of the Radio Spectrum

The ability of electromagnetic waves to propagate great distances has necessitated international cooperation in spectrum management. The headquarters for this effort is the International Telecommunications Union (ITU) in Geneva, Switzerland. Exhaustive files of registered users are maintained there, and published as multi-lingual volumes arranged in order of frequency. These tables of frequency allocations are generally available for inspection at FCC field offices and monitoring stations. Additionally, they may be purchased from the ITU directly, or from domestic distributors. Some technical libraries subscribe to this ITU service. The cost is substantial, and listings are often out of date or inactive.

A much more useful source of active frequencies and callsigns, classified by agencies and services, is the Confidential Frequency List by this author, and published by Gilfer Associates (PO Box 239, Park Ridge NJ 07656).

Traditionally, the users of the radio spectrum are divided into two categories: Broadcasters (both domestic and international) and Utilities (everything else!).

In the United States, all government transmitting frequencies are coordinated through the master file of the Interdepartmental Radio Advisory Committee (IRAC), which reports directly to the Department of Commerce Office of Telecommunications. Management of non-government stations is the responsibility of the Federal Communications Commission (FCC).

Naturally, the FCC and IRAC must cooperate closely. Retrievals from the government master file and the frequency assignment lists are available to frequency managers of various government agencies. Discrete frequencies may be designated secret, confidential, or unclassified.

Each year, the IRAC Secretariat processes in excess of 50,000 frequency applications. These include some 20,000 new assignments, and the remainder divided among modifications, renewals, or deletions. The majority of these are in the 2 to 20 MHz portion of the shortwave spectrum.

GOVERNMENT USERS

The United States Government operates millions of transmitters, representing an investment of over fifty billion dollars (Fig. 2-1). It enjoys exclusive use of 25 percent of the radio spectrum, and shares an additional 45 percent with non-government users. Nearly half of these frequencies are allocated to the military, with the US Navy having the distinction of being the world's largest user of the air waves.

US Government radio facilities fall into four major categories:

Conventional Radiocommunication Facilities. Voice, telegraphy, teletype and facsimile classified as point-to-point, air-to-ground, ship-to-shore, land mobile, satellite relay, and so forth.

Radar and Radiolocation. Used for the detection of ships, aircraft, missiles, and storms.

Radionavigation. Provides safe routing for ships and aircraft.

Telemetry. Involves the remote sensing and transmission of encoded data, usually hydrological, meteorological, or satellite probes.

Department of Defense. According to IRAC reports, the DOD utilizes a staggering amount of communications (approximately half of all government assignments) and it absorbs about 50% of the entire output of the electronics industry!

Radiocommunications for command and control is effected through the Defense Communications System (DCS), constituting some 80 percent of the National Communications System, involving nearly three million personnel worldwide. DCS serves over 1900 U.S. and 1200 foreign locations. The NCS includes (in addition to the DOD) the State Department, Federal Aviation Administration, National Aeronautics and Space Administration, and General Services Administration. The nearly 70 high-frequency stations of DCS provide over 300 voice channels, many with derived teletype; additionally, there are over 3000 trunks supported by tropospheric scatter, microwave line-of-sight systems, and 14 satellite links. Altogether, these flexibilities add up to some 35,000 voice and teletype channels providing nearly five million

channel miles!

Active Army in a typical field maneuver is concentrated in an area about the size of the state of Utah and uses more than 75,000 transmitters to support combat and service forces.

The *Army Defense Command* is encharged with missile defense of strategic locations in the continental United States. It requires radio for control, radar, and communications.

Army Aviation uses eighty airfields in the US to maintain some 12,000 aircraft, requiring radio communications and navigation.

The *Corps of Engineers* (Civil Works Division) utilizes some 3000 radio stations maintaining communications, Radar, and telemetry in the US, Alaska, and Puerto Rico. Civil Defense preparedness links are maintained by US Army HF networks.

The *U.S. Navy* has nearly 600 ships and submarines, 6800 aircraft, and a million personnel utilizing the extensive Naval Communications System's 28 major and minor transmitting complexes with some 3000 transmitters. The largest users of communications are 51 major Navy and Marine Corps Air Stations, 10 shipyards, and 3 test ranges. Within the fleet are an additional 40,000 transmitters, with another 52,000 communications transmitters in naval aircraft. In all, the U.S. Navy and Marine Corps maintain some 300,000 transmitters.

The *U.S. Air Force* uses some 700,000 personnel to operate 130,000 transmitters worldwide to support the following commands and services of the United States Air Force:

The *Aerospace Defense Command (ADC)* provides identification, surveillance, and interception of aircraft, missiles, and space vehicles penetrating U.S. facilities, drone control and target scoring, tactical UHF facilities, and HF single-sideband circuits.

Tactical Air Command (TAC) communications are mostly portable and mobile; this is the command responsible for immediate response to sudden crises, such as those in the Mideast and Southeast Asia.

The *Strategic Air Command (SAC)* with one third of our SAC bombers eternally airborne, serves as one of America's greatest deterrents to a surprise enemy attack. Communications with the EC-135 airborne command post are occasionally heard on USAF single-sideband circuits.

The *Military Airlift Command (MAC)* has Presidential, VIP, and emergency airlift assignments as its primary responsibility. During national catastrophies at home and abroad, this important command provides emergency airlift of food and medical supplies.

The *Air Force Communications Service (AFCS)* links all Air Force commands worldwide, AFCS engineers and operates the enormous fixed and mobile communications facilities during both peacetime and emergencies.

Other Air Force users include missile test ranges, the Electronic Systems Division, Special Weapons Center, Aeronautical Systems Division, and more.

The *U.S. Coast Guard* protects the security and safety of the US shorelines by its network of 270 ship-to-shore radio stations, 215 radiobeacon transmitters, a fleet of 1100 radio-equipped craft, 170 aircraft, and accompanying aeronautical radio stations.

The *Department of Justice* enforcement of Federal laws is effected through several high-mobile agencies, including the U.S. Border Patrol, Drug Enforcement Agency, Federal Bureau of Investigation, and U.S. Marshalls. Base stations, repeaters, mobile and portable

Fig. 2-1a. US fleet communications (courtesy of Motorola).

Fig. 2-1b. Antenna structure aboard US Navy ship.

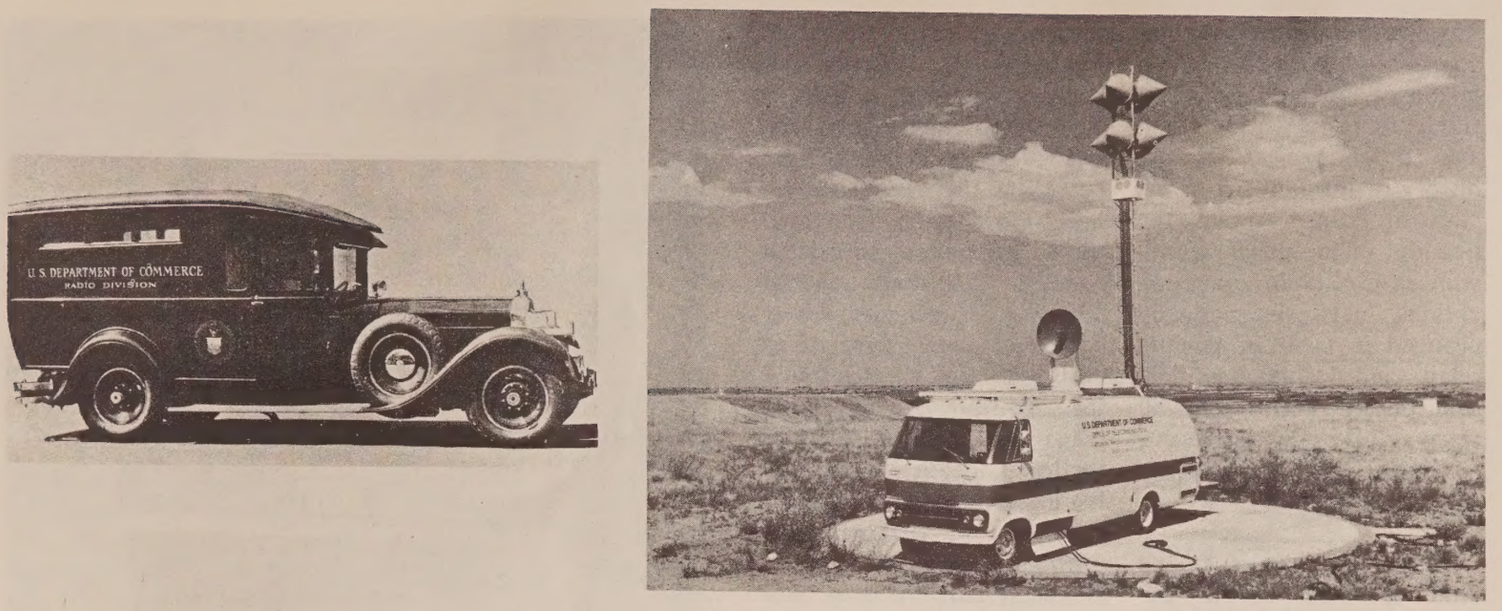

Fig. 2-2. The old and the new. (Office of Telecommunications spectrum measurement vans.)

units are widely distributed.

The *Department of the Interior* manages our nation's natural resources through the communications of several agencies, including the Bureau of Land Management, Bureau of Indian Affairs, Bureau of Sport Fisheries and Wildlife, Bureau of Reclamation, Southwestern Power Administration, and Bonneville Power Administration. Additionally, all radio-related facilities of several Pacific protectorates including American Samoa are the responsibility of this department. These functions entail well over 40,000 fixed and mobile transmitters.

The *Department of Agriculture's* 20,000 radios are used by the US Forest Service to protect 200 million acres of our National forests and waterlands.

The *Department of Commerce's* National Weather Service has more than 400 offices in the U.S. and its possessions. The NWS National Meteorological Center assists the World Meteorological Organization of the United Nations, and vital storm information is detected and dispersed by the National Hurricane Center. The National Oceanic and Atmospheric Administration maintains several communications networks in its research programs. The National Environmental Satellite Service provides essential environmental data from its eyes in space, while the Environmental Research Laboratories monitor water, earth, and space.

The *Energy Research and Development Administration (formerly AEC)* has the task of policing the hazardous science of radioactive materials and requires elaborate safeguards, including reliable communications. A high frequency single-sideband/telemetry network links ERDA headquarters, its principal offices, and its mobile convoys. ERDA utilizes 2400 fixed/repeater stations, 8,000 mobile/portable stations, and numerous radiation monitoring transmitters.

The *Treasury Department* has the protection of the President, Vice President, and their families as a prime responsibility of their Secret Service Division. Major law enforcement regarding counterfeiting, smuggling, forgery, and bootlegging is also Treasury Department responsibility. Four hundred base and repeater stations, and 5000 mobile/portable units are distributed throughout the U.S.

The *US Information Agency* is in charge of a major propaganda effort, Voice of America, which is broadcasting constantly to the world its messages of American policy, in 36 different languages. VOA has 41 transmitters at five locations in the U.S. broadcasting shortwave programs overseas, some of which are relayed by 73 additional transmitters on foreign soil.

Fig. 2-3. Inside the Office of Telecommunications van. (Photo courtesy of OT.)

The *National Aeronautics and Space Administration's* Man in Space program has captured more attention than any other project in the history of mankind. With the close of Project Apollo, the historic billion-dollar worldwide NASA radio communications network gradually changed in favor of satellite relay and cable hard-line. Still, point-to-point radio will always play a significant, although redundant, role in the space program.

Other Federal users of the radio spectrum include the Federal Communications Commission, Department of State, National Security Agency, U.S. Postal Service, Veterans Administration, Tennessee Valley Authority, and the Department of Health, Education, and Welfare.

NON-GOVERMENT USERS

The non-Federal Government users of the radio spectrum are more familiar to most listeners. These include: Broadcast services; industrial and scientific; business, aeronautical, maritime, amateur and experimental, public safety and emergency services; land transportation, educational, domestic satellite, public correspondence, and local and state government.

ENFORCEMENT

Policing of the radio spectrum is a staggering task. In 1927 the Department of Commerce outfitted its first mobile monitoring laboratory to check broadcast stations (Fig. 2-2). As the numbers of users of the spectrum grew, so did the work load on the simple van. In 1934 a new Communications Act provided for the establishment of the Federal Communications Commission. The FCC would now monitor all non-government assignments, and the Office of Telecommunications Policy would manage Federal Government usage. Recently, an elaborate new mobile Radio Spectrum Measurement System has been completed which is capable of analyzing frequency usage from 40 kilohertz through 19 gigahertz. Spectrum analysis is effected by a computer controlled receiver. Repeated spectral sampling is recorded; time-history data are then analyzed later to determine the density of frequency usage as monitored at a particular location (Fig. 2-3). It's interesting to note that in spite of the elaborate receiving capabilities of the mobile system, the only two-way communication maintained is by a single common carrier mobile telephone!

LISTENING AND THE LAW

Although we have discussed in some detail the management of radio transmissions, what are the regulations in the United States regarding "listening in" on privileged communications? Along with creating the FCC, the 1934 Communications Act also stated its secrecy of communications protection in section 605:

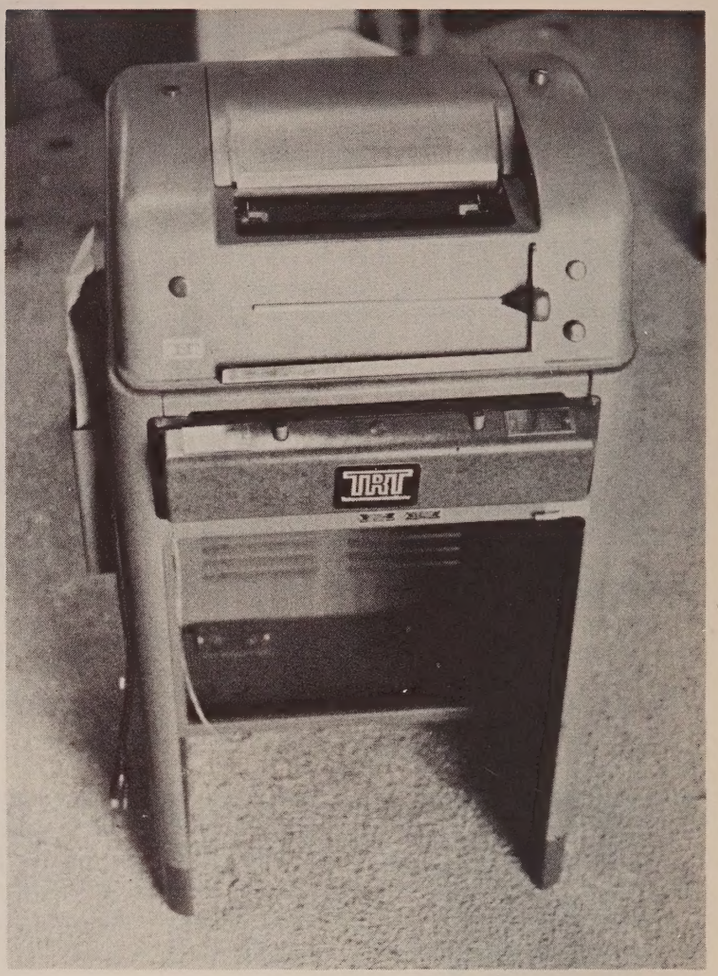

Fig. 2-4. Teletype Model 28RO page printer.

"No person receiving or assisting in receiving, or transmitting, or assisting in transmitting, any interstate or foreign communication by wire or radio shall divulge or publish the existence, contents, substance, purport, effect, or meaning thereof, except through authorized

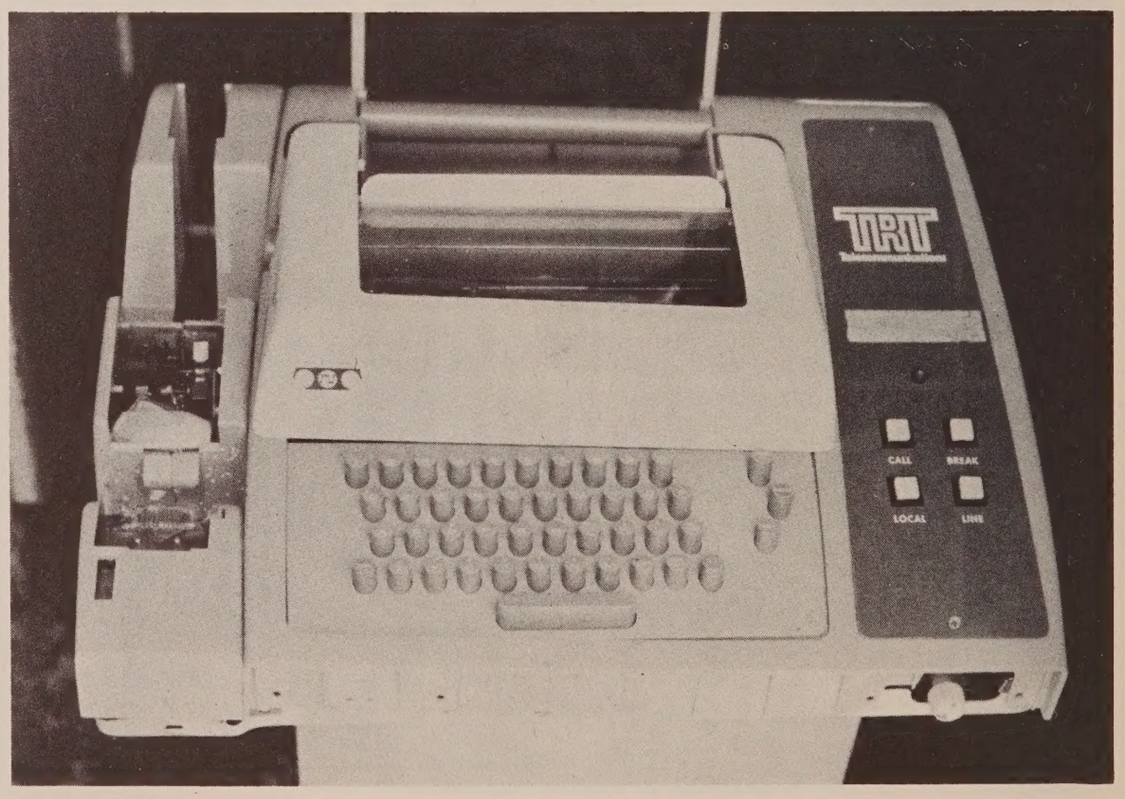

Fig. 2-5. Teletype Model 32ASR page printer with reperforator.

channels of transmission or reception, to any person other than the addressee, his agent, or attorney, or to a person employed or authorized to forward such communication to its destination, or to proper accounting or distributing officers of the various communicating centers over which the communication may be passed, or to the master of a ship under whom he is serving, or in response to a subpoena issued by a court of competent jurisdiction, or on demand of other lawful authority; and no person not being authorized by the sender shall intercept any communication and divulge or publish the existence, contents, substance, purport, effect, or meaning of such intercepted communication to any person; and no person not being entitled thereto shall receive or assist in receiving any interstate or foreign communication by wire or radio and use the same or any information therein contained for his own benefit or for the benefit of another not entitled thereto; and no person having received such intercepted communication or having become acquainted with the contents, substance, purport, effect, or meaning of the same or any part thereof, knowing that such information was so obtained, shall divulge or publish the existence, contents, substance, purport, effect, or meaning of the same or any part thereof, or use the same or any information therein contained for his own benefit or for the benefit of another not entitled thereto: PROVIDED, that this section shall not apply to the receiving, divulging, publishing, or utilizing the contents of any radio communication broadcast, or transmitted by amateurs or others for the use of the general public, or relating to ships in distress."

This act is enforced by the FBI. In summary, a listener is prohibited from divulging the nature of a communication not intended for him to hear, and additionally prohibits him from using that intercepted information for personal gain. It has been judged both legal and moral for any listener to monitor to his heart's content *any radio transmission of any nature whatsoever;* just don't talk about what you heard!

There are some local ordinances which forbid police monitors in automobiles.

In virtually every other major country of the civilized world, laws regarding monitoring communications range from licensed regulation to absolute prohibition.

We now know who the users of the spectrum are; *where and how to listen* will be the topics for the re-

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THE HAL RVD-1005 IS AN ALL ELECTRONIC
PRINTER REPLACEMENT FEATURING:
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MANUAL
LINE FEED
LTRS
UNSHIFT ON SPACE
SPEED WPM(BAUD)
POWER

Fig. 2-6. A modern character generator and RTTY video display. (Courtesy HAL Communications Corp.)

mainder of this book.

ALLOCATIONS

Although far more detailed lists are available from the ITU, OTP, and FCC, table 1 will serve as a basic guide to the primary services likely to be encountered during routine listening. The most productive frequency ranges for monitoring government (military, agencies, etc.) communications are *italicized;* in the HF range, non-government users share these bands as well. International fixed public stations are point-to-point long distance services available for public correspondence. Aeronautical references include both aircraft in flight and fixed ground stations supporting flight services. Radiobeacons are directional navigational aids. All VHF/UHF voice communications are FM unless otherwise noted. HF voice communications are usually SSB, although some AM is still heard on the lower frequencies. Almost without exception, all voice transmissions below 2 MHz are full-carrier AM. No voice transmissions will be heard below 160 kHz.

Table 1.

FREQ. KHZ.	*TYPES OF SERVICES PRIMARILY HEARD*
10-14	Maritime radiobeacons
14-160	Navy CW/RTTY; international fixed public; radiobeacons
160-250	Foreign broadcasting
200-415	Radiobeacons; aeronautical weather
415-535	Maritime telegraphy
535-1605	Standard broadcasting
1605-2000	Radiobeacons; amateur
2000-3500	Aeronautical, maritime
3500-4000	Amateur
4000-5000	Aeronautical, maritime, international fixed public
5000-5950	Aeronautical
5950-6200	International AM broadcasting
6200-7000	Aeronautical, maritime, international fixed public
7000-7300	International AM broadcasting, amateur
8195-8815	Maritime
8815-9500	Aeronautical, international fixed public
9500-9775	International AM broadcasting
9775-11700	Aeronautical, international fixed public
11700-11975	International AM broadcasting
11975-12330	Aeronautical, international fixed public
12330-13200	Maritime
13200-14000	Aeronautical, international fixed public
14000-14350	Amateur
14350-15100	Aeronautical, international fixed public
15100-15450	International AM broadcasting
15450-16460	Aeronautical, international fixed public
16460-17360	Maritime
17360-17700	Aeronautical
17700-17900	International AM broadcasting
17900-21000	Aeronautical, international fixed public
21000-21450	Amateur
21450-21750	International AM broadcasting
21750-22000	Aeronautical, international fixed public
22000-22720	Maritime

TYPES OF EMISSIONS

A casual scan of the shortwave frequencies will reveal a variety of modes of radio transmission; voice may be AM, FM, or single-sideband; other modes include teletype, facsimile, Morse code, telemetry. There are a variety of techniques to accomplish one common goal: *The delivery of information by an electromagnetic signal.*

Basically, all radio waves have four fundamental characteristics: frequency (and thus wavelength), amplitude, modulation, and polarization. Modulation may be used to vary the frequency or phase of the signal (now called a carrier wave) as in FM, or to vary the amplitude of the signal (AM). A third type of emission, wide-band pulse modulation, is rarely used below 1000 MHz.

The more common types of emissions the listener will encounter are classified in Table 2.

Identifying these signals on the air comes with practice. However, there are a few helpful hints which might make the job easier, AØ is sometimes called a "dead carrier"; when it is tuned in on a receiver, the S-meter will rise showing its presence, and background noise will generally grow quieter. If the receiver beat-frequency oscillator is switched on, a stable tone will be heard confirming its presence. Transmitted carriers maybe left in the AØ mode for a number of reasons: as frequency markers, propagation indicators, directional or navigational signals, or merely to indicate to other users that the frequency is occupied. *A1* is common International Morse code telegraphy; the transmitter's carrier is switched on and off at a timed rate (the duration of dots and dashes). Without the receiver BFO switched on, *A1* sounds like a series of rapid thumps, erratically fluctuating the background noise of the received frequency; the BFO provides the note which makes the signal readable. Most *A1* (also called continuous wave, or CW) is ship-to-shore and aeronautical telegraphy, both military and domestic. Other users include point-to-point law enforcement agencies (especially foreign) and press. Its use is decreasing steadily with the increase in radioteletype and common carrier services. *A2* is much rarer, but is readable on receivers without BFOs. It is sometimes used to transmit clandestine messages to foreign agents with modest receiving equipment and tuning skills. Not all tone-modulated telegraphy, however, is directed toward spies!

A3 is standard voice or music, as transmitted by both domestic and international broadcasters below 30 MHz. Although decreasing in use as a communications mode below 30 MHz, it is still the dominant mode of the aeronautical voice operation at VHF and UHF.

A carrier wave itself carries no useful information other than centering the passband of the receiver; it is merely a vehicle to convey information via its sidebands, or by encoded keying. Similarly, although two sidebands are created during modulation because of phase reversal,

22720-25000	Aeronautical, international fixed public
25000-25330	Industrial land mobile
25330-25600	Government
25600-26480	International AM broadcasting, broadcast remote pickup
26480-26950	Government
26950-26960	International fixed public
26960-27540	Citizens band, industrial land mobile
27540-28000	Government
28000-29700	Amateur

FREQ. MHZ.	
29.7-50	Land mobile, business, industrial, public safety, government
50-54	Amateur (FM/SSB/AM)
54-72	TV broadcasting
72-76	Low-power industrial communications; 75 MHz radiobeacon
76-108	TV and FM broadcasting
108-118	Aeronautical radiobeacon
118-136	Aeronautical (AM)
136-138	Earth satellites
138-144	Government and military portable communications
144-148	Amateur (FM/SSB/RTTY)
148-150.8	Government and military portable communications
150.8-162	Land and maritime mobile, public safety, business, local government
162-173.4	Government portable and mobile communications
173.4-174	Business mobile
174-225	TV broadcasting, amateur, telemetry
225-400	Military and aeronautical communications
400-406	Weather telemetry
406-420	Government portable and mobile communications
420-450	Amateur, government radiobeacon
450-512	Land mobile (business, industrial, public safety)
512-806	TV broadcasting
806-949	Land mobile (business, industrial)
949-960	International fixed public
960-1215	Aeronautical radiobeacons

only one sideband is necessary to transmit information. Therefore, it is advantageous to conserve power and spectrum space by transmitting only one sideband and no carrier. This is the technique known as single-sideband, suppressed carrier *(A3J)* transmission.

Because of the geometric imbalance of such a received signal, the carrier wave must be restored by the receiver BFO (or product detector); otherwise, the voice is garbled. *A3A* single-sideband has the carrier reduced, but not suppressed; some carrier is purposely inserted to make tuning easier (often automatically phase-locked) at the receiving end of the circuit. When manually tuned, the BFO is switched on, and the resulting heterodyning tone (beat note) is adjusted by tuning the receiver until it gets lower and disappears (zero beat). This setting will provide the greatest intelligibility or clarity of the signal. Reduced carrier single-sideband is widely used in common carrier long distance radiotelephone circuits of the international fixed service.

A3J is suppressed carrier single-sideband, and is the dominant mode of two-way voice communication below 30 MHz. It is characterized (as is A3A) by a muffled, garbled sound without the BFO on, hardly recognizable as a voice. When the BFO or product detector is switched on, the received signal is tuned for the most natural voice sound.

A4 and *A4A* facsimile finds widespread use in the transmission of weather maps. Facsimile signals sound surprisingly similar to a phonograph record stuck in a repetitious scratchy groove, repeating patterns of clicks.

A5 is television, found as slow-scan on the amateur frequencies in the HF spectrum, and fast-scan in the commercial broadcast VHF/UHF region. It will seldom (if ever) be encountered elsewhere. Slow scan has a characteristic rapid chirping sound, while the harsh buzz of a fast-scan video signal is unmistakable in the VHF region.

F1 is common radioteletype; with the BFO switched on, it will sound like a rapid, randomized barrage of dual-pitched dots. Frequency shift keying is also occasionally used for International Morse code transmission, but its use will be obvious as the distinct dots and dashes are readily recognizable.

F2 is used the same way as F1, the difference being the presence of a modulated tone or tones on the carrier without the receiver BFO in use. It is also for selective-call tone signalling in VHF/UHF paging systems.

F3 is standard FM voice or music; it is narrow bandwidth for communications, and wideband for commercial broadcasting. It is only found above 25 MHz.

F4 facsimile is the mode used in the 137 MHz band for Automatic Picture Transmitting weather satellites.

RADIOTELETYPE

Teletype is the technique of typing a message on a keyboard, which, in turn, activates a printout on a carriage at a remote location (Fig. 2-4). In its simplest form it often resembles a circuit (or "loop") consisting of two inter-connected electric typewriters, the keyboard of each activating both printing mechanisms. When the teletype signal is used to modulate a radio transmitter, it is called radioteletype, or RTTY ("RATT": US Navy). RTTY signals may be found throughout the radio spectrum, from VLF (US Navy global network) to VHF and beyond. Weather information, press news copy, and even government communications are prevalent.

The digital process of encoding each character of the keyboard is binary, with current flowing during "mark," and the circuit being opened during "space." This binary information is transmitted by radio in the form of frequency-shift keying, in which either a modulated tone shifts frequency (audio-frequency shift keying, or AFSK), or the carrier frequency itself shifts back and forth (Frequency Shift Keying or FSK). The amount of shift is important since the receiver passband must be properly narrowed and filtered to include the two

Fig. 2-7. A modern facsimile machine. (Courtesy Stewart-Warner.)

binary frequencies, but exclude any random noise or false signals which would cause the teleprinter to respond in error. This selectivity is achieved both in the receiver, and in the RTTY converter filters.

Traditionally, a shift of 850 Hz has been widely used with the time-honored machine speed of 60 words per minute. With the advent of sharp-selectivity technology, frequency shift has been reduced considerably, although higher speeds require correspondingly wider bandwidths. Commercial shifts now include 425, 240, 170, 85, and even 70 Hz; speeds encountered usually will be 60, 66, 75, and 100 words per minute.

To receive RTTY, the listener needs two pieces of equipment attached to a stable receiver; a demodulator (variously called a converter, tuning unit, or TU), and the teleprinter. These two pieces of equipment make up the terminal. The demodulator may be connected to the receiver IF circuit as a discriminator, or more commonly, to the audio output.

Teletype converters may be constructed from scratch (many recent diagrams have appeared in amateur radio magazines), although many are available commercially (such as the popular HAL ST-6) and on the surplus market (such as the CV89/URA, often selling for under $100). Used teleprinters ("Teletype" is a registered trademark) are also readily available. Surplus machines may have been made by Kleinschmidt, Western Electric, and the Teletype Corporation. Page printers (models 15, 26, 28, and 32) are the most common (Fig. 2-5), printing their copy on a roll or folded package of ten-inch paper. Older machines like the model 15 are often available for $25 to $50, depending upon condition. They are not capable of 100 wpm operation.

Typing reperforators like the model 14 print out their copy on a continuous tape, while simultaneously punching the tape to encode it for later playback or re-transmission. The model 14 is capable of 100 wpm operation because of its smaller size.

Composite machines which consist of a page printer and keyboard, tape reader, and a perforator, include models 19, 28ASR, and 32ASR. For monitoring stations, keyboard-less read-only machines (RO suffix) are recommended for lower cost and less maintenance.

A more recent addition to radioteletype has been the introduction of video terminals (Fig. 2-6). By this technique, a demodulator drives a character generator which, in turn, presents its copy digitally as a display on a standard TV set (or video monitor for enhanced resolution). Advantages of a video system include noiseless copy, reduced equipment space, and lower maintenance. The singular disadvantage is loss of permanent copy; as with facsimile and slow-scan television, however, if a permanent record is desired, the demodulated audio may be tape recorded on an inexpensive cassette for later playback and display, or permanent printout.

A logical evolution from RTTY video technology is the recent appearance of a Morse code display.

FACSIMILE

Facsimile is the electronic transmission and subsequent electromechanical reproduction of graphic information. This includes maps, weather satellite pictures, press photographs, or any other non-verbal images. The original specimen is scanned photoelectrically; the resultant signal may be sent by wire, or used to modulate a transmitter. The received signal is used to drive a stylus (electrolytic and electrothermal processes) or a narrow-beamed lamp (photosensitive process). Both the original work and the copy paper are normally placed on synchronized rotating drums so that printout will be analogous to photodetection of the original work (Fig. 2-7).

Synchronization is of the utmost importance in facsimile; the 60 Hz power line frequency is normally used to provide the synchronous drum speed. Proper phasing is also essential; the start of each scan line must coincide with the beginning of a line on the copy paper.

Drum-writing speeds are commonly multiples of 60 lines per minute (60, 120, 180, and 240), with a scan density of 96 lines per inch. For a given density, the best resolution is provided by focusing the light spot (in photosensitive reproduction) to solidly fill in between scan lines; thus, for a density of 96 lines per inch, the spot is ideally adjusted to a diameter of 1/96 inch.

Ultimate resolution of the received image depends on several other factors: slow drum speed (often several minutes per picture), high scan density with fine light beams, bandwidth of the signal, and type of paper or process used.

An alternative reproduction technique involves the photographing of a received image as presented on a long persistence cathode-ray tube.

One of the most common surplus facsimile machines available is the electrothermal Western Union Telefax transceiver built by Seeburg. Often sold in the twenty-dollar region, it is readily applicable to experimental facsimile monitoring.

Table 2.

Amplitude Modulation

A0	Unmodulated continuous carrier wave
A1	On-off (keyed) carrier wave (telegraphy)
A2	Tone-modulated, keyed carrier wave (telegraphy)
A3	Full-carrier telephony (double sideband)
A3A	Single-sideband, reduced-carrier telephony
A3B	Telephony with two independent sidebands
A3J	Single-sideband, suppressed carrier telephony
A4	Facsimile with full carrier
A4A	Facsimile with reduced carrier, single-sideband
A5	Television
A7A	Multi-channel wideband telegraphy, single-sideband, reduced carrier
A9B	Independent sideband, mixed modes

Frequency Modulation

F1	Frequency-shift keying (teletype or telegraphy)
F2	Tone-modulated teletype or telegraphy)
F3	Telephony
F4	Facsimile

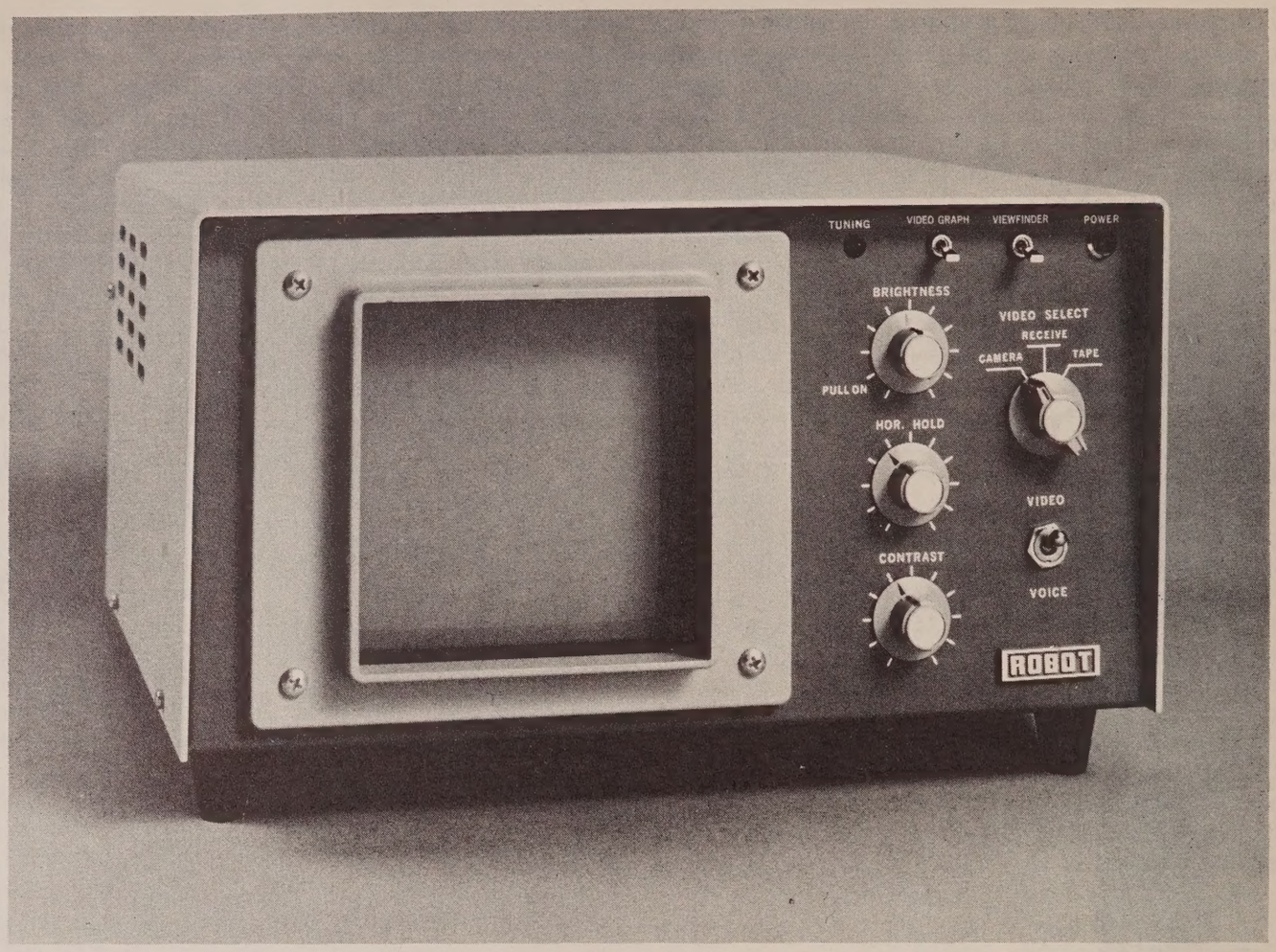

Fig. 2-8. Slow-scan television monitor. (Courtesy Robot Research.)

Fig. 2-9. Slow-scan television converter. (Courtesy Robot Research.)

Although facsimile signals are scattered throughout the long and shortwave spectrum, a popular VHF band for reception is that of the weather satellites surrounding 137 MHz. HF signals include those of the U.S. Navy fleet weather (3357, 4975, 8080, 10865, 16410, and 20015 kHz) at NSS Annapolis and U.S. Air Force KWAF (4502.5, 10185, 14550, and 19955 kHz).

Further details concerning facsimile reception are beyond the intent of this book, but interested readers are referred to the list of publications at the end of this chapter.

TELEVISION

Television permits the instantaneous long distance transmission of moving images (Fig. 2-8). High resolution, however, necessitates the wide bandwidth of fast-scan systems, and is never found below VHF. Slow-scan techniques are capable of good resolution, and have inherently narrower bandwidth (typically 1200-2300 Hz) which is allowed anywhere in the radio spectrum where speech transmission is found. Unfortunately, because of the slower scanning rate, the transmission of moving images is not practical; SSTV is therefore confined to the transmission of facsimile-type material: maps, pictures, diagrams and charts, and so forth. Its use is rarely encountered outside the amateur radio frequencies (3845, 7171, 7220, 14230, 21340, and 28680 kHz).

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Radio Spectrum Handbook by James M. Moore (Howard B. Sams)
ABC's of Shortwave Listening by Len Buckwater (Howard B. Sams)
Realistic Guide to Police, Fire, and Aircraft Radio by Leo G. Sands (Radio Shack)
Code of Federal Regulations, volume 47 Telecommunication, Parts 0-19 (U.S. Government Printing Office, Washington DC)
Frequency Allocations (RCA Frequency Bureau)
Introduction to Shortwave Listening by Louis M. Dezettel (Radio Shack)
Shortwave Listener's Guide by H. Charles Woodruff (Radio Shack)
World Radio-TV Handbook by J. M. Frost (Billboard Publications)
Police Call Magazine (Lebanon NJ 08833)
CRB Research (PO Box 56, Commack NY 11725)

Listeners Clubs:
Longwave Club of America, 11425 Albers St. #5, N. Hollywood CA 91601
SPEEDX, PO Box 321, Santa Ana CA 92702 (Utilities Handbook)
FRENDX, PO Box 989, Altoona PA 16603 (Shortwave Broadcast Journal)
American Shortwave Listeners Club, 16182 Ballad Ln, Huntington CA 92649
Newark News Radio Club, PO Box 539, Newark NJ 07101
Midwest DX Club, PO Box 8522, Miami FL 33124
National Radio Club, PO Box 127, Boonton NJ 07005

Teletype:
Beginners RTTY Handbook by RTTY Journal (PO Box 837, Royal Oak MI 48068)
Specialized Communications Techniques for the Radio Amateur (ARRL)

Sources of Used RTTY Equipment and Parts:
Typetronics, PO Box 8873, Ft. Lauderdale FL 33310
Vardon and Associates, 930 N. Beltline, Suite 140, Irving TX 75061
Jim Cooper, 651 Forest Ave., Paramus NJ 07652
C.B. Goodman Co., 5454 S. Shore Drive, Chicago IL 60615
National Teletypewriter Corp., 207 Newtown Road, Plainview NY 11803
Lawrence R. Pfleger, 532 W. Wilson St., #1, Madison WI 53703

Facsimile:
Specialized Communications Techniques for the Radio Amateur (ARRL)
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Chapter III

Surveillance

The majority of surveillance operations fall into a small number of uses: law enforcement, government espionage, industrial spying, domestic investigation, and protective security. Bugging devices, designed primarily for voice detection, are either wired microphone circuits or radiating transmitters. Both are small enough to be easily hidden and escape casual discovery. Some sophisticated voice bugs use subcarrier modulation to escape detection by common monitors.

For the most part, room bugs are simple devices; low-powered (1-600 milliwatts) oscillators with a range from a few hundred feet to many blocks, and a battery life of several weeks. They are planted by the agent (operative) for a specific period of concentrated monitoring of his subject (target). For extended periods of operation, the device has to be retrievable for battery replacement, or powered from other sources such as power lines, telephone current, "free power" (detected and rectified radiation from a nearby broadcast transmitter), or even solar-battery recharging (if physically possible).

The most popular frequency bands for surveillance transmitters can be found in Table 3.

If the transmitter is planted on a moving vehicle as a pulsing tailing transmitter ("bumper beeper"), it may be located by directional antennas on the operative vehicle, such as an RDF loop; or less conspicuously, co-phased whips (mounted on each front-fender cowl, the signal will null when the transmitter is directly in front of or behind the operative's vehicle and centered between the two whip antennas). While the direction is indicated by a null in signal, the distance is approximated by the relative signal strength. Obviously, an S-meter is essential for accurate tracking, and so is experience. This technique may also be employed to find the location of an illicit transmitter.

Commercial "bug detectors" are usually variations on a field-strength meter. They are high-gain, broadband devices which require a minimum of tuning. In actual use, they are adjusted to maximum sensitivity without keying their alarm circuit, and then walked around the suspected area carefully searching for an additional RF level which will trigger the alarm. (Fig. 3-1)

A less-expensive, and often highly-satisfactory, approach is with the use of a multiband portable radio. With a foreknowledge of common bugging frequencies, this technique is reasonably successful. The antenna may be collapsed to prevent interference from high- powered broadcast stations, and the room combed carefully, tuning the receiver through its range.

Out-of-band transmitters (72-76 MHz) may often be detected on their second harmonic (144-152 MHz) using an inexpensive multiband radio. Debugging is most successful in the early morning hours when TV and FM stations are off the air (i.e., Sunday at 5 AM!).

If you detect a clandestine transmitter in operation while tuning these frequencies, think objectively about its purpose before acting impulsively; remember, Section 605 of the 1934 Communications Act specifically forbids an accidental listener to divulge the existence or nature of a private transmission by the *sender*; but is this the *agent* or the *subject*? After considering all the legal

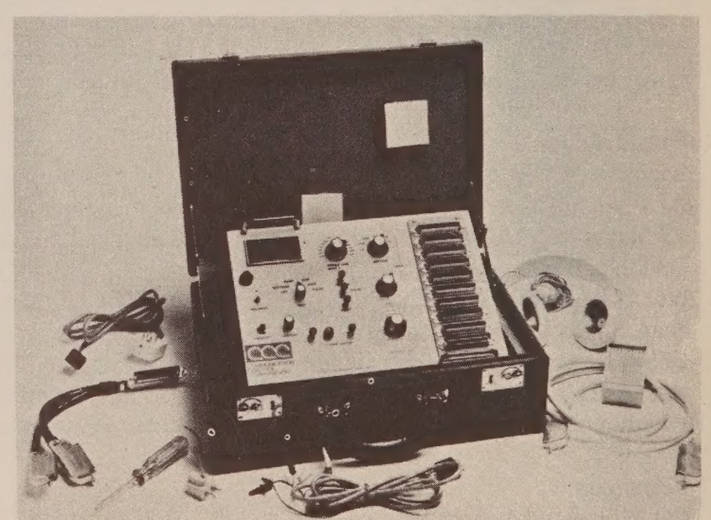


Fig. 3-1. Sophisticated "bug" detector and accessories. (Courtesy Communication Control Corporation.)

Table 3.

88-115 MHz (89, 110) common for professional investigators
72-76 MHz commercial wireless-mike band; high-powered transmitters may be heard for miles
30-50 MHz (49 MHz) common for professional investigators and law enforcement agencies; bumper beepers
150-174 MHz military intelligence, domestic and government agencies, law enforcement; long-range transmitters run several watts, and are manufactured by well-known companies.

and moral ramifications of disclosure, you may wish to advise the target, notify the police or FCC, defeat the device by interference or removal, feed it erroneous information, or do nothing at all. Information acquired by a legal surveillance device can save the lives of many innocent persons. Let your conscience be your guide and check with a local attorney before acting; laws vary from state to state, or jurisdiction to jurisdiction.

REMOTE SURVEILLANCE AND IDENTIFICATION OF A CLANDESTINE TRANSMITTER

In most cases, an outside antenna is a dead giveaway as to the frequency band of operation of the unknown target transmitter; additionally, the type of antenna suggests its use. Simple ground planes suggest local coverage, as do low antennas; elaborate arrays suggest directional long distance capabilities; lack of a rotator on a directional antenna indicates point-to-point operation, while a rotator on a directional array suggests mobile or network participation.

A simple frequency determination may be made utilizing a frequency counter and a short antenna as part of a mobile or portable package. If the target operation may be approached within a few hundred yards, the signal should be detectable during transmissions by a sensitive frequency counter. A sensitive, amplified wideband field strength meter may be used to signal a transmission; an inexpensive multiband portable radio may be used as a monitor to verify operation. Weak or distant transmissions may be enhanced by the use of a preamplifier ahead of the counter, or by feeding the counter from the output of the RF stage of the receiver.

Naturally, if the transmitter is within ready monitoring range of the operative's fixed monitoring station, it is far more convenient, but the farther away the transmitter is, the more difficult it is to identify among other users of the spectrum. A sharply- directional receiving antenna is certainly of help if substantial geographical separation is essential.

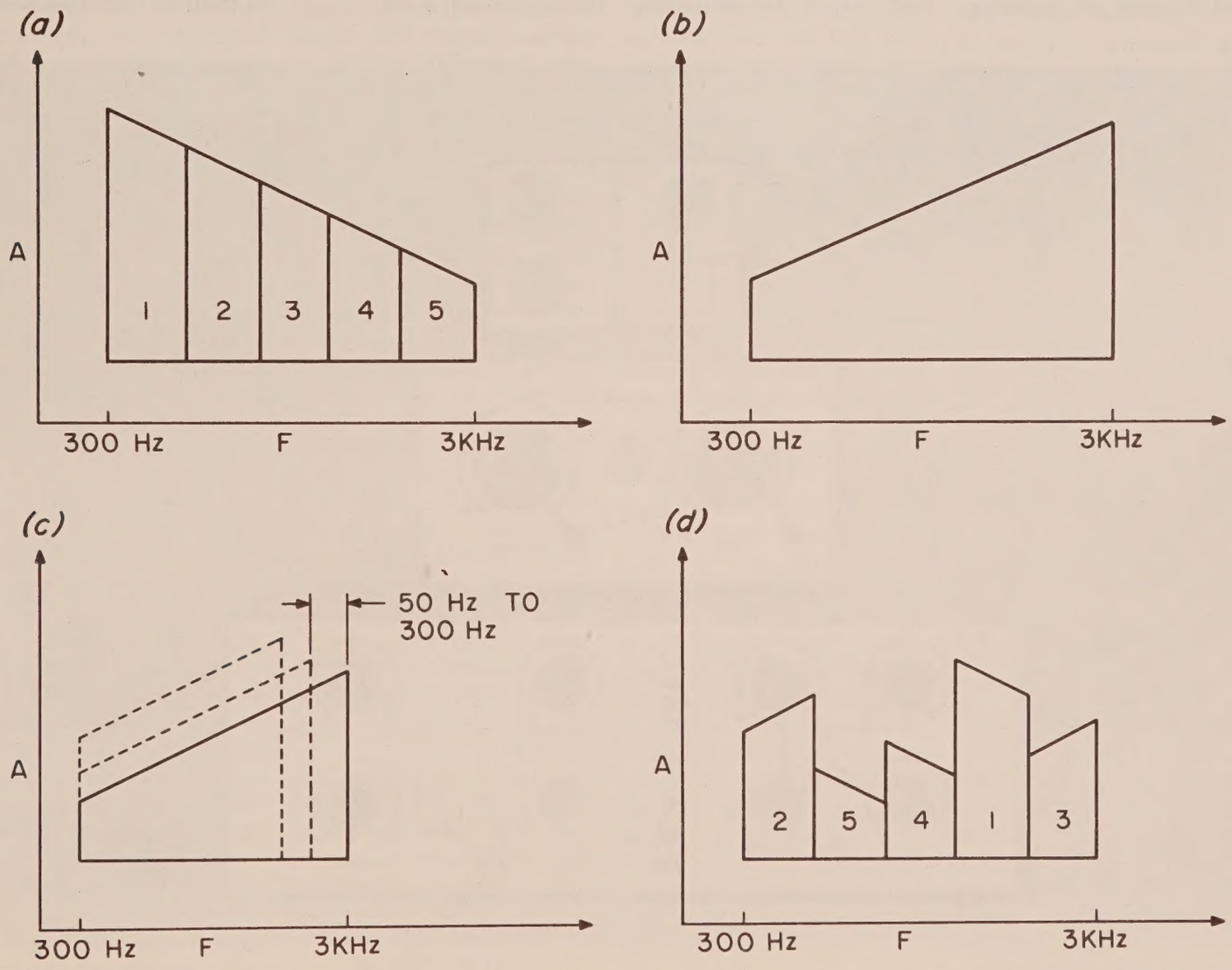


Fig. 3-2. The normal speech spectrum (a) may be scrambled a number of ways, including simple inversion (b), frequency hopping inversion (c) and band splitting (d).

SECURE TRANSMISSIONS

Because of the widespread use of low-cost police monitors and communications receivers available to the general public, informational security has become a serious problem in law enforcement, as well as in government and industry. Digital teletype is often used in police vehicles in preference to voice, especially for personal and vehicle identification.

Although the use of coded signals helps to a limited degree, voice and data scramblers are used where the ultimate in secure communications is required (Fig. 3-2). Several techniques are used to accomplish this, with decoding becoming progressively difficult depending upon the complexity of the system. Typical speech techniques are presented here, listed in order of increasing security (but decreasing intelligibility).

Speech inversion. Through the use of a heterodyning oscillator, voice frequencies are literally inverted in the 300-3000 Hz spectrum. A simple demodulator at the receiving end consists of another oscillator on the same inversion frequency as the transmitter, and a balanced detector. This receiving system re-inverts the inverted voice band back to normal speech.

A few manufacturers are now offering inexpensive, but effective descramblers for the receiver market. One of these is available from Don Nobles (Rt. 7, Box 265B, Hot Springs AR 71901).

Frequency-hopping inverters. To prevent casual decoding of simple inversion, some inverters are encoded and synchronized to continually change their inversion frequency. Additionally, tone masking may be employed by which audio tones are injected to cover intelligence, and sequentially filtered out at the receiver.

Bandsplitters. The speech spectrum may be filtered into four or five separately- inverted bands, transmitted, and separately re-inverted by the receiving demodulator. Or, the separated bands are interchanged in their relative positions in the speech spectrum, transmitted, and reordered by the matching receiver decoder. "Rolling-code" bandsplitters constantly rearrange the filtered speech-band increments several times each second, making decoding an overwhelming task. In many cases, by the time the laborious task of decoding a secure system like this is completed, the information is old.

Pseudo-random noise masking. Secret military intelligence is now transmitted with masking techniques which render the transmission virtually undistinguishable from the background noise. A digital-code generator phase-shifts the voice signal which has been rearranged by the filtering and separating of the high-energy portion of the speech pattern; the result sounds like noise due to the large number of modulation products and fast switching of the encoder. The decoder must detect the transmitted code and use it to guide the phase shift and speech-band rearrangement for intelligibility.

Obviously, a system that sophisticated is extremely expensive, and unlikely to be encountered in domestic or commercial communications.

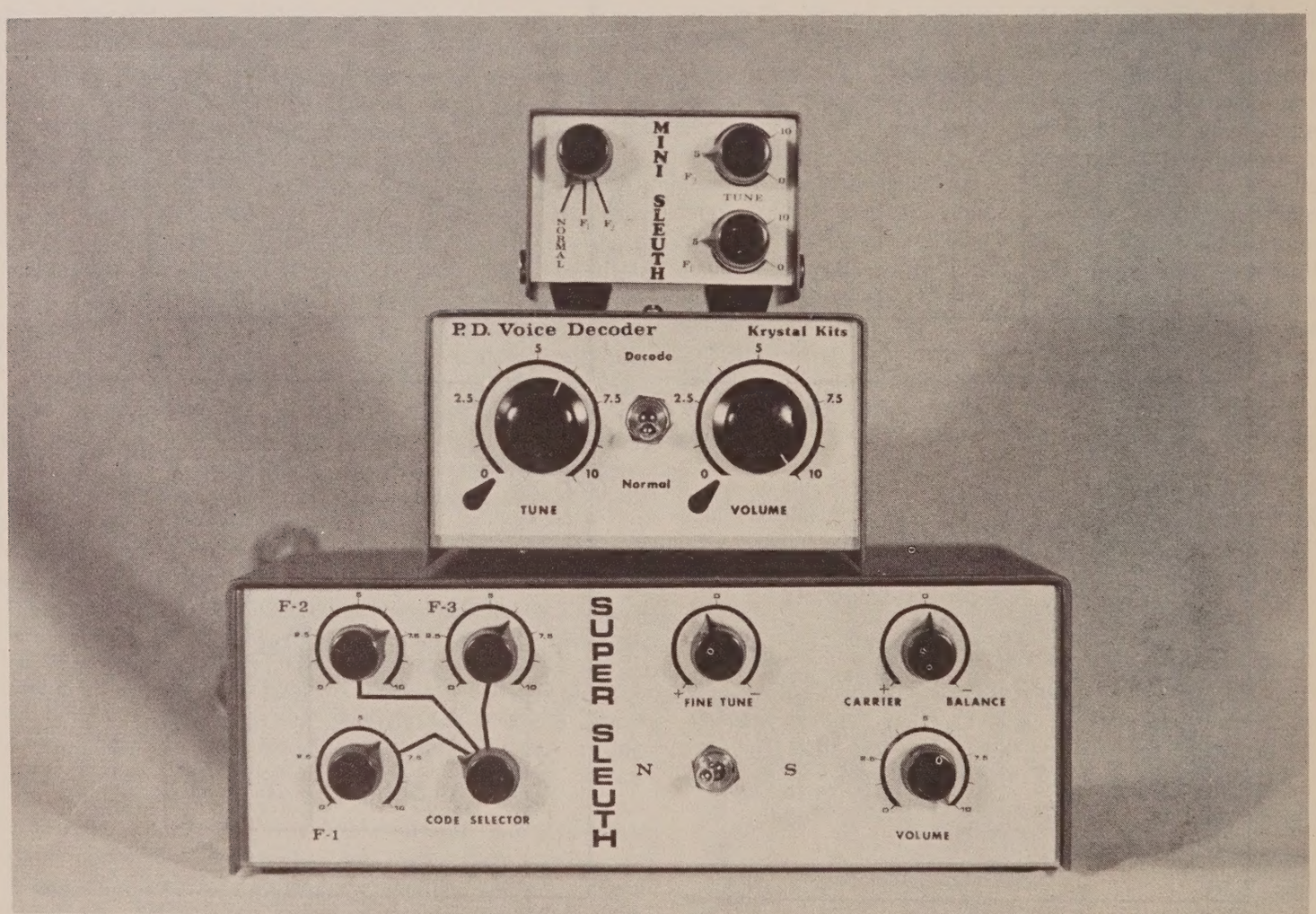


Fig. 3-3. Three useful scrambled speech decoders. (Courtesy Krystal Kits.)

Chapter IV

Station Layout Considerations

When unlimited funds are available for an effective monitoring or surveillance operation, an enormous number of equipment combination possibilities become apparent; if the monitoring position is reduced in scope to a casual hobby, financial limits radically restrict those possibilities. The illustrations in this chapter are intended to serve as examples to guide the prospective listener toward an effective design within the limits of his budget, see Fig. 4-1 . The systems to be described vary in cost from over one hundred thousand dollars (Raytheon 1150 and accessories) to under three hundred dollars (Lafayette/Radio Shack approach) . . . and increments between.

Simplicity is always advised; complex systems require fatiguing attention to details, and can become a maintenance and operational nightmare because of system interdependence.

As a first step, it is wise to decide what categories of transmissions are to be monitored; then determine the logical frequency ranges which will be utilized. Continuous-coverage "DC to daylight" frequency capability is considerably more expensive than those installations designed for specific frequency ranges. Dial readout accuracy is another important consideration; resolution of one kilohertz or better is expensive, but highly recommended. The casual monitoring needs of the occasional "shortwave listener" variety are most economically served by using a good-quality receiver, and merely approximating station points on a logging scale using known frequencies as reference points, see Fig. 4-2 .

Similarly, antennas must be chosen with their primary intended uses foremost in mind. Portable, short-range and non-critical hobby applications will find small, simple antennas entirely satisfactory; fixed, long-distance professional installations will require careful antenna design to optimize frequency coverage, polarization, directivity, and efficiency, see Fig. 4-3 .

A common-sense approach to station design will help prevent dissatisfaction and unnecessary expense.

VACUUM TUBES OR SOLID STATE?

During the first half of the century, radio circuitry was custom-tailored around the vacuum tube; the cat's whisker and galena crystal detector were the first solid state electronic device. With the discovery of solid state amplification in germanium crystals (Bell Laboratories, 1947), a new era of electronics was born.

The first transistors were as primitive as the first vacuum tubes; they certainly could not match the performance of sophisticated tube technology. But the spark was there, and the drive of industry has produced solid state refinements undreamed of just a few years ago.

The earliest transistorized receivers had many drawbacks, these were intermodulation, cross-modulation, poor dynamic range, and high noise to name but a few. But the state of the art has grown to a point (and will continue to grow) where none of these objections is valid any longer. To the contrary, the transistor and subsequent integrated circuit technology have enormous advantages over out-dated vacuum tubes, including:

1. No filament which resulted in wasted power, warmup time, heat dissipation, characteristic drift, deterioration, and eventual burnout.
2. Smaller physical size; lighter and more easily mounted; less stray-signal pickup.
3. Lower operating voltage and current; simple batteries or small power supplies; less shock hazard; less stress on associated components.
4. More efficient.
5. Sturdier; no glass envelope, suspended elements, or microphonics.
6. Longer life — decades instead of months.
7. No vacuum to be maintained; less pressure-critical.
8. Greater choice of design parameters and characteristics.
9. Compatible with modern low-cost, high-performance miniature components.

In addition, modern solid state devices are equal to tubes in low noise, and have excellent signal handling ability (wide dynamic range); admittedly, internal capacitance must be reduced still further to equal that of miniature tubes.

Yes, solid state circuitry, when properly designed, is highly effective; it is the

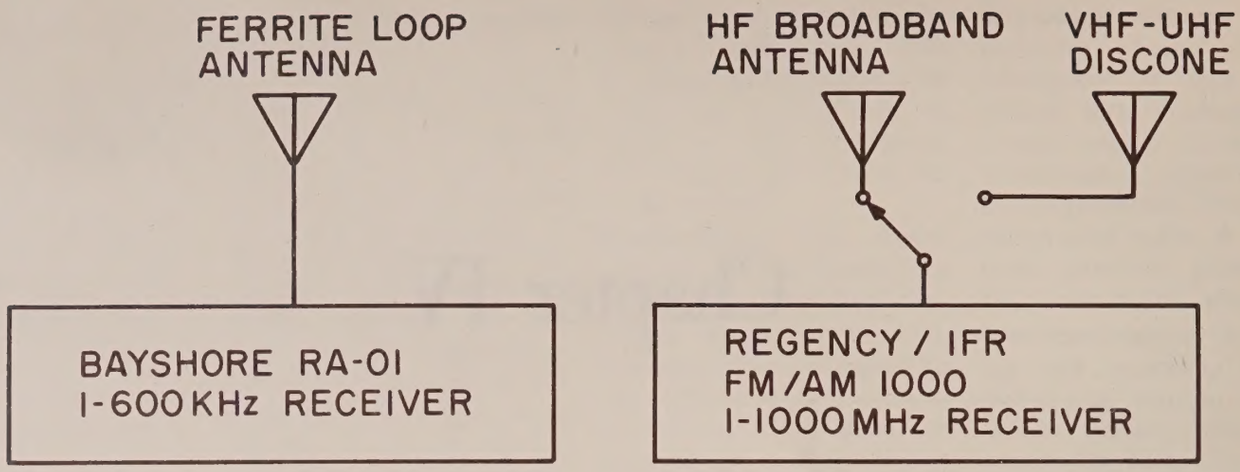


Fig. 4-1a. A compact, fully portable and expensive wide-range receiving installation.

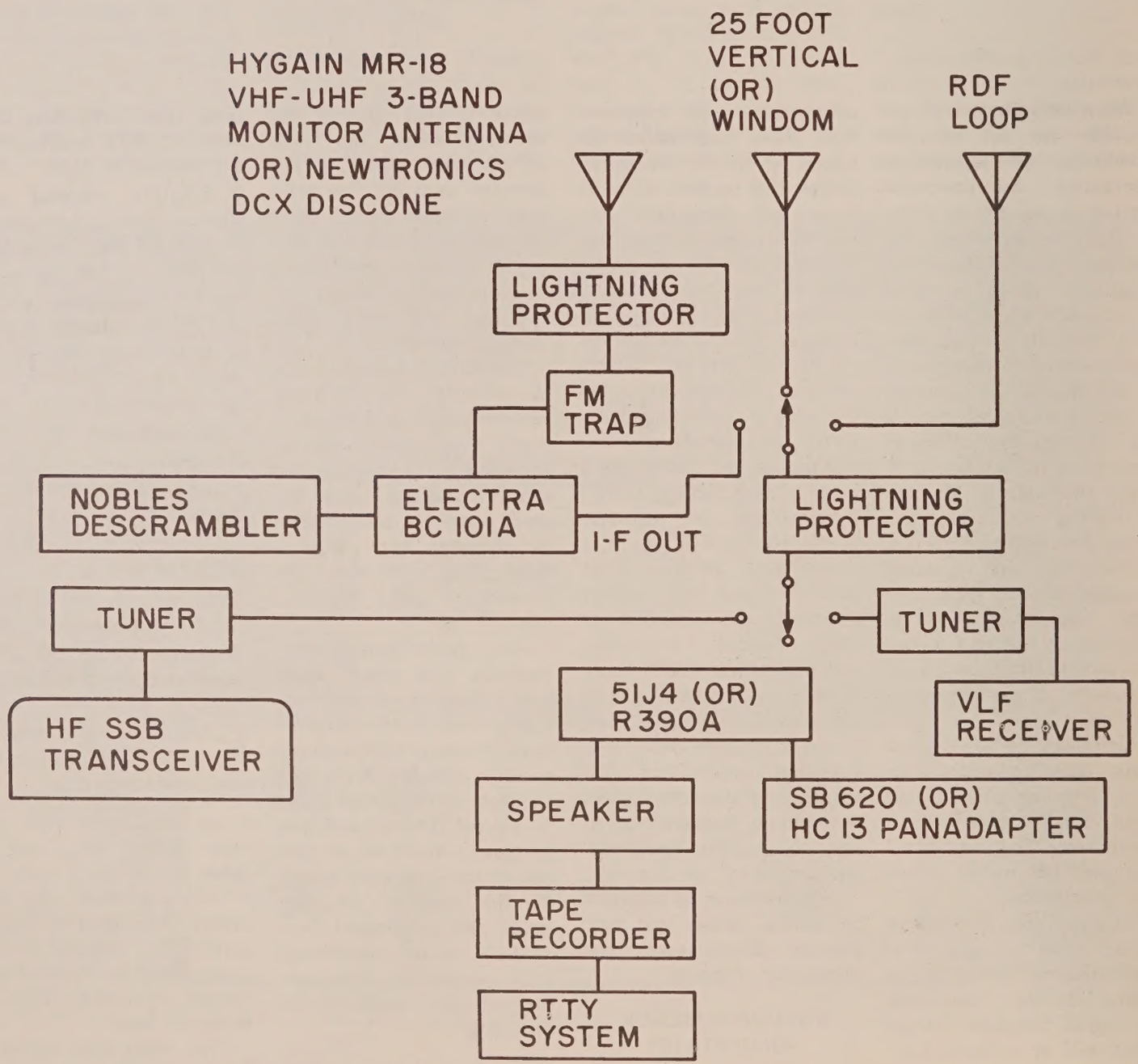


Fig. 4-1c. A highly flexible economical monitoring system with a ham transceiver provision.

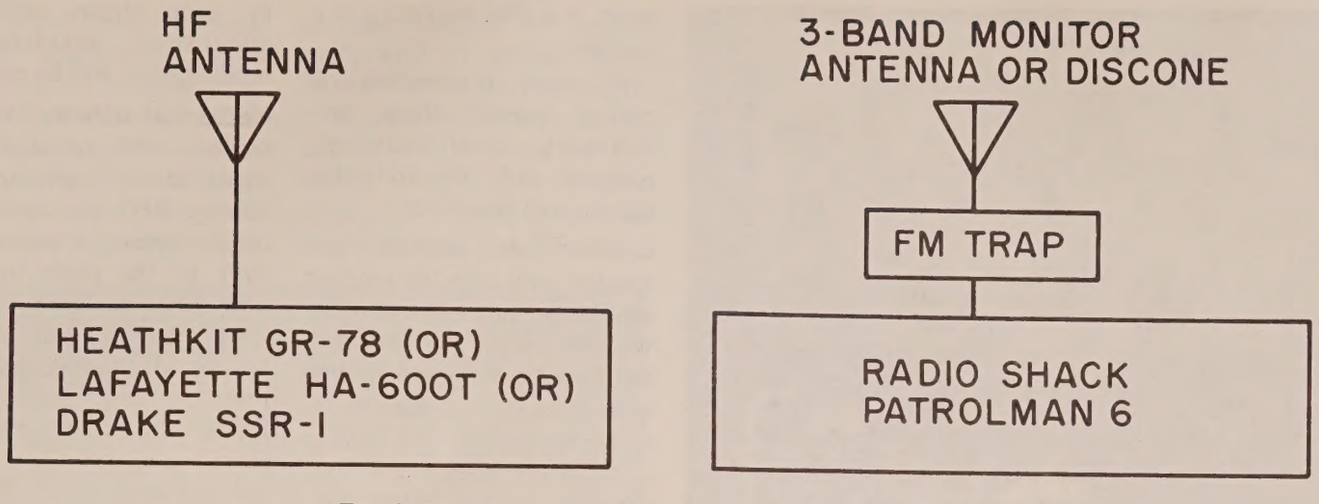


Fig. 4-1b. A low-cost listening post for the casual listener.

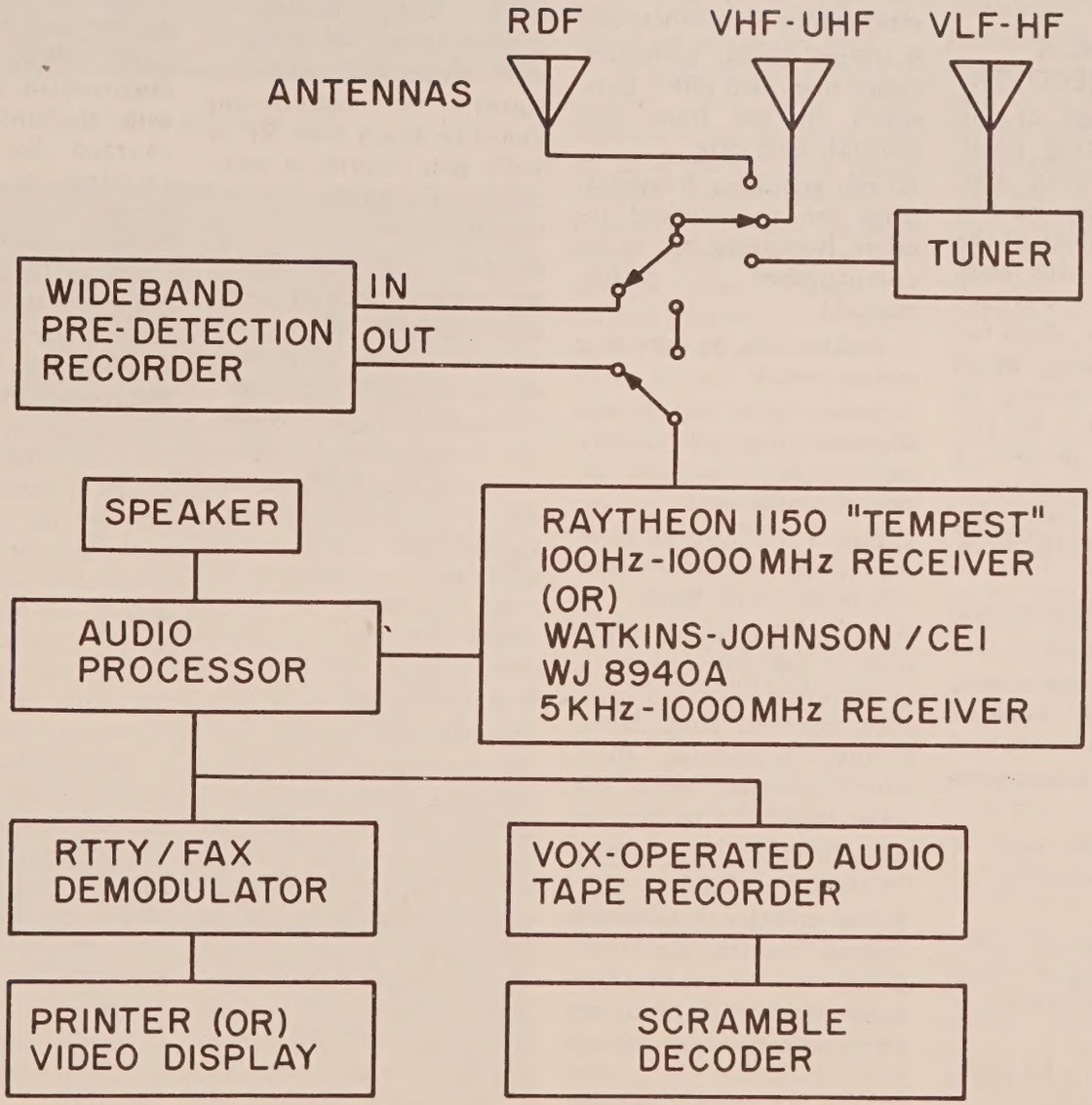


Fig. 4-1d. A monitoring installation if cost is no object.

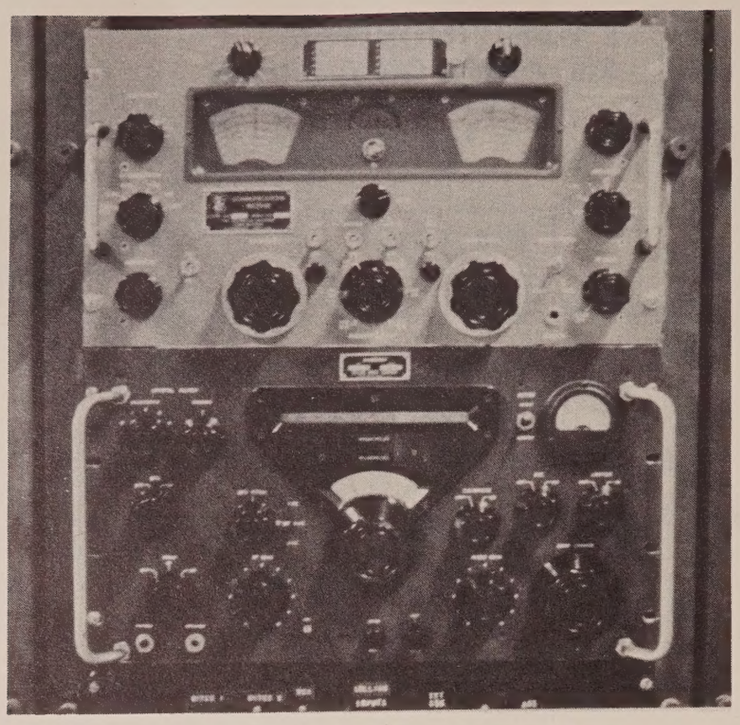


Fig. 4-2. Two popular receivers: the Temco GPR-90 and the Collins R-388/51J4.

technology of the present and certainly of the future, see Fig. 4-4.

SELECTING A SHORTWAVE RECEIVER

Since the heart of any effective monitoring installation is the receiver, painstaking consideration must be given to every aspect of the selection of this vital component (Fig. 4-5). If you have located a receiver which has the frequency range which you desire, and it seems to be reasonably priced, a few precautions may prevent a serious error in judgement.

As a general rule, stay away from a shortwave receiver which:

1. Cost under $100 when new
2. Is over 25 years old
3. Has warped circuit boards, or tube sockets mounted directly on circuit boards
4. Does not have a selectivity control
5. Shows extensive signs of wear, abuse, corrosion, or neglect
6. Reveals charred components or wiring, or insulation-leaking transformers or filter capacitors
7. Was built from a kit unless expertly constructed
8. Displays poor solder connections or sloppy add-ons, missing cabinet and panel hardware indicating careless maintenance or modifications
9. Utilizes bipolar transistors rather than field effect transistors in the front end (tuner) if solid state
10. Has enormous frequency range for a low-priced receiver (something has to be compromised ... *performance!*)

Additionally, be wary of a receiver which:

1. Shows worn or burred alignment slugs and trimmers resulting from frequent or careless re-alignment
2. Uses a dial cord to drive the tuning capacitor when turning the tuning knob
3. Has non-factory modifications or additions, or missing or incorrectly-replaced hardware, controls, plugs, jacks, knobs, accessories; these almost invariably reduce the resale value of a receiver, as well as hold the receiver's performance suspect
4. Has crowded bandspread, making fine tuning difficult
5. Has a "cleaned-for-fast-resale" look; light dust and corrosion are normal with age

NOTE: An owner's manual, or at least a schematic diagram, is a vital accessory to a receiver.

If your prospective receiver passes these preliminary qualifications, proceed with the following operational check-out:

Connect an antenna and speaker, and turn the receiver on. Allow one or two minutes warmup while sensing any overheating. With the volume control set at minimum, listen for hum in the speaker ... a sure sign of a bad filter capacitor in the power supply! *Slight* hum is acceptable.

Controls. Rotate volume control up and down, leaving it at a comfortable listening level. Rotate other controls, listening for noisy, erratic performance. In most cases noisy controls can be cleaned with TV-tuner-type aerosol sprays available for that purpose from radio parts houses, but it is well to note that the control *could* be worn or defective. No oscillation squeals or motorboating should be heard with RF or audio gain controls at maximum. Frequency tuning should feel smooth.

Bandswitch. With the BFO on and a signal tuned in on the upper-frequency range of the receiver, rotate the bandswitch back and forth; on a mechanically-stable receiver, the signal should return closely to its original setting. As with noisy controls, contact spray *usually* reduces an erratic bandswitch condition. Be careful not to get aerosol spray on oscillator components which causes long-term drift.

Thermal stability. A good communications receiver will not drift from its set frequency, even on a high range, after about five minutes warmup time. With the receiver adjusted to a signal on the upper frequency range and the BFO turned on, listen for a noticeable drift in pitch. Drift makes listening unbearable on all modes except AM. If bandswitch contacts are clean and oscillator tubes are in good shape, and drift continues, servicing, or modification will be required.

Mechanical stability. With the receiver still adjusted to a signal at its high-frequency setting, BFO on, tap the receiver cabinet; a wavering or shift in the pitch indicates unstable oscillator design. This may or may not be serious, depending upon the operator and the physical layout of his monitoring position.

Sensitivity and Receiver Noise. In order to satisfactorily detect weak signals, modern receivers are designed for high-sensitivity, low-noise performance. Typically, a shortwave receiver should be capable of receiving a signal of less than 5 microvolts for a receiver noise reduction of at least 10 decibels. Since calibrated signal generators are rarely available to the prospective buyer, he must do the best he can subjectively. With the antenna disconnected (or better yet, with the antenna terminal shorted to the ground terminal or chassis), no signals should be heard. This indicates good shielded construction (although it could indicate a dead receiver!). If steady, unmodulated signals are detected, they are probably spurious signals generated within the receiver itself; if they are not too severe or numerous, they are normal for many moderately-priced receivers. If modulated signals from the outside are being detected, it could indicate leakage through cabinet or wiring, or possibly a high-powered transmitter nearby.

Now, connect a few feet of wire to the antenna terminal. Unless the receiver is located in an unusually well shielded room, many signals should be heard throughout the shortwave spectrum, especially in the 8-15 MHz range. At night, signal strengths are even more pronounced and more numerous at lower frequencies. In the absence of signals,

background noise should increase appreciably upon connecting the antenna wire. The 27 MHz citizens band is often a good spot to check the sensitivity of a receiver at high frequencies; when the band is active, many distant stations should be copied easily with an outside antenna only a few feet in length.

If sensitivity seems to die out at the low end of the tuning ranges, the bypass capacitors probably need to be replaced in the RF, oscillator, and mixer stages.

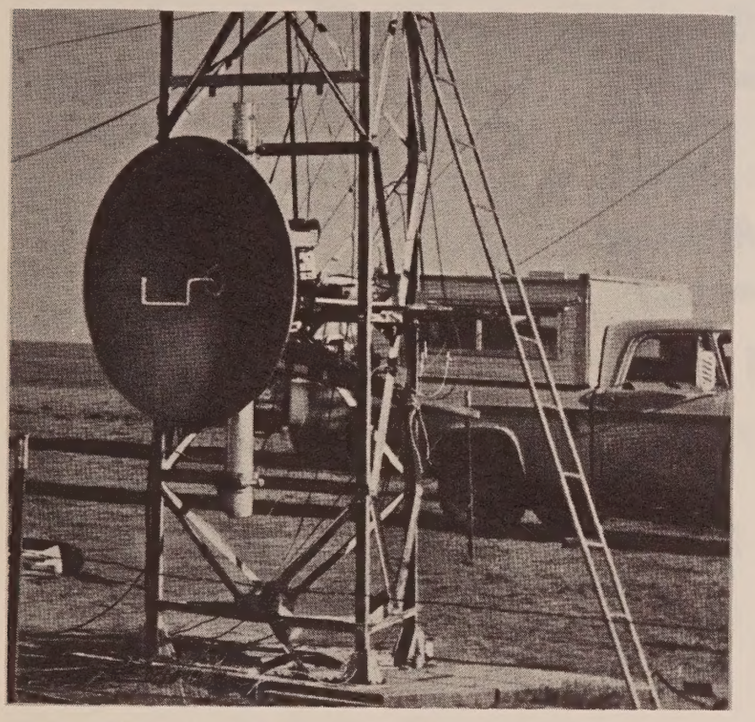


Fig. 4-3a. A parabolic dish.

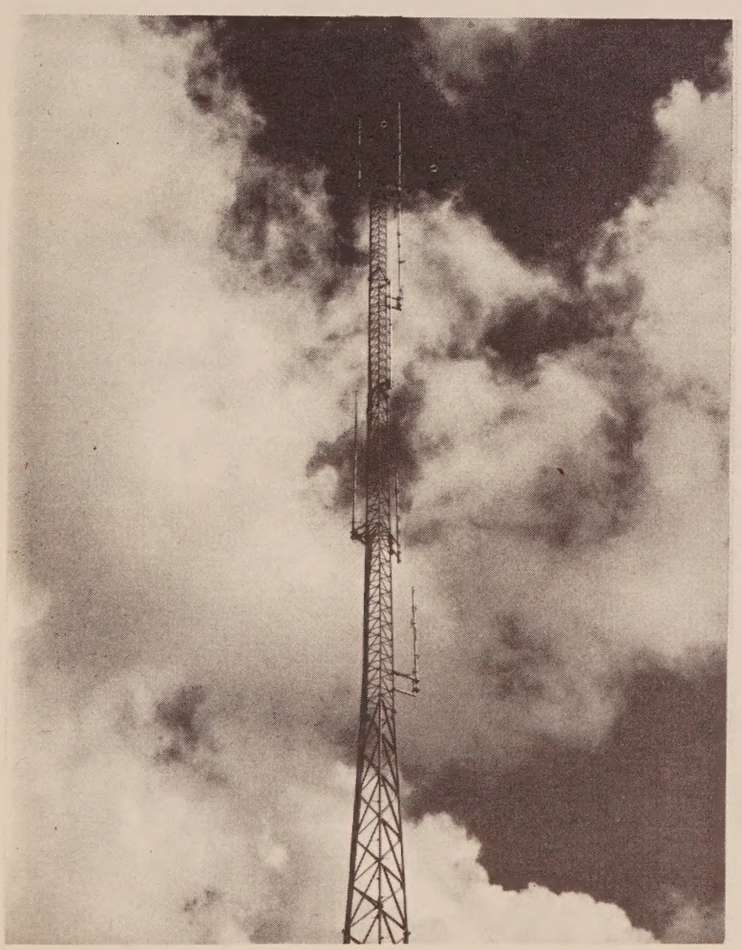


Fig. 4-3b. A vertical array.

Selectivity. The ability of a receiver to isolate a single signal from among many closely spaced signals is a measure of its selectivity; the width of that channel is called the passband, and the characteristic shape of the passband curve is called the skirt. A well-designed receiver will have variable selectivity to accommodate different signal bandwidths, and skirts will have steep sides to reject adjacent channel interference, see Fig. 4-6.

Selectivity is achieved in three sections of the receiver: the tuned radio frequency stages, the intermediate frequency stages, and the audio stages. The use of mechanical filters in the IF stages is the most popular and effective way to achieve sharp selectivity with steep skirts; Q-multipliers, crystal filters, and tuneable notch/peak filters are also widely used.

To test the selectivity of a receiver, tune in a signal which is being interfered with by an adjacent station; this is usually characterized by a heterodyne (whistle or beat note) superimposed on the desired signal. Adjust the variable selectivity control for rejection of the unwanted signal without destroying the intelligibility of the desired signal; some readjustment of the tuning dial may also be necessary to help center the passband. IF filter loss may be determined by reading the S-meter while switching the filters in and out of the circuit and peaking the tuning dial; approximate the loss at 6 dB per S-unit. If the attenuation is too great, the filter is either defective or the IF circuitry is misaligned.

Control Interaction. With the BFO on and an upper frequency range signal tuned in, rotate the antenna trimmer, RF gain control, and selectivity controls; no appreciable change in pitch should be heard, demonstrating good stage isolation.

Images. Signals which "shouldn't be there" are often the result of inadequately-designed circuitry, signals mixing and producing more signals! This is one of the disadvantages of superheterodyne circuitry. Images are detectable as whistles (heterodynes) which sweep across the passband as the receiver dial is tuned *without* the BFO on. Images are most severe in the higher frequency ranges, so listen for them above 10 MHz. One sure-fire way to detect images in most receivers is to listen for the 27 MHz citizens band repeat itself at about 28 Mhz; a receiver with good image rejection will suppress these phantom signals 40 dB or more.

Intermodulation and Front-end Overload. A serious problem for those listeners who are physically situated near high-powered transmitters is "intermod," multiple images appearing in the tuning range of the receiver due to the inability of many receivers to handle such enormous signal strengths. Even if the receiver does not produce images, it may become desensitized by the presence of such a high RF level. One of the most satisfactory ways of reducing or eliminating this problem (other than moving) is by the insertion of a wavetrap in the antenna line. This technique will be discussed in the chapter on interference.

Anti-noise Capability. Few of us enjoy the luxury of a noise-free environment; modern conveniences aggravate the problem of electrical interference everywhere. Hair driers, fluorescent lights, trucks and cars, light dimmers, power lines, and a myriad of other sources of irritation can wreak havoc with the sensitive receiving installation. An effective noise limiter is essential. It should be capable of filtering or removing noise pulses without destroying the integrity of the desired signal. Shunt and series noise limiters smooth out the noise pulses, but slightly degrade

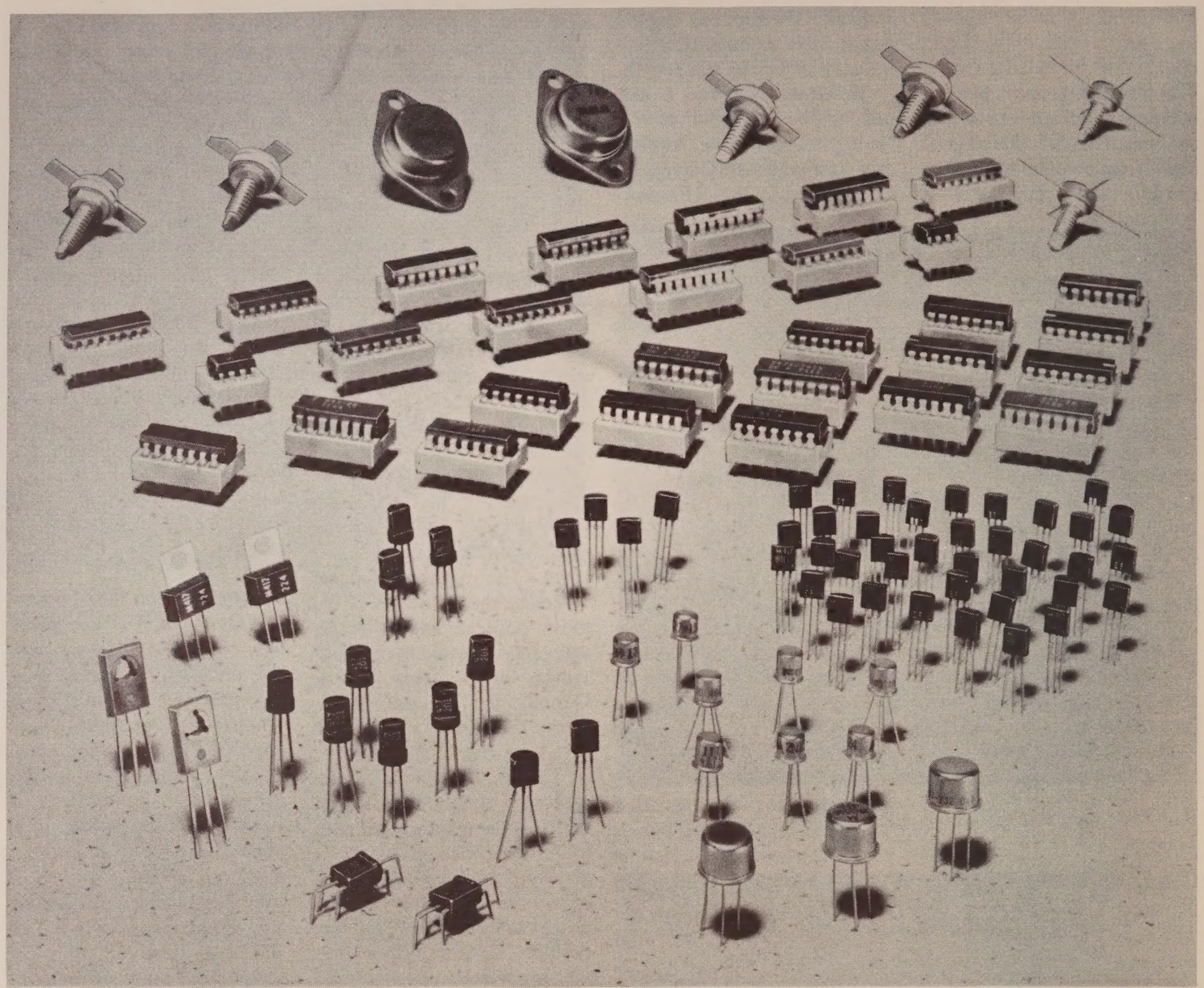


Fig. 4-4. Integrated circuits and transistors now dominate the communications field. (Courtesy Heathkit.)

the intelligibility of the signal.

Test the noise interference handling capability of the receiver by turning on a source of electrical noise and activating the noise-reduction circuit of the receiver in the presence of a weak voice or music signal; a high-quality anti-noise circuit (like a noise blanker) will not seriously distort the voice or music, but will substantially lower the noise level.

Dial Accuracy. Although accurate readout of frequency is secondary to casual listeners, it is of utmost importance to the serious listener. Accuracy of 1 kHz or better is desirable; check dial tracking throughout its tuning range. If the dial accuracy is not acceptable,

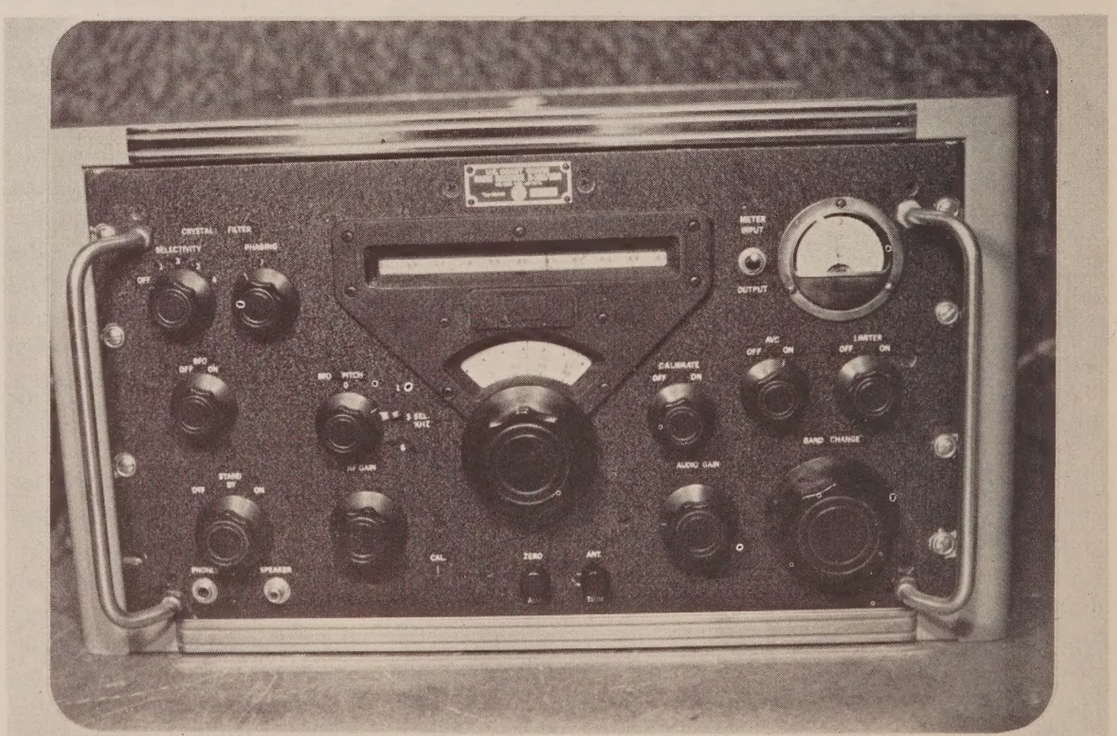


Fig. 4-5. Although an older receiver, the Collins 51J4 continues in popularity.

Table 4.

MODERATE COST
*Drake SPR4** (& FS-4 synthesizer)
Galaxy R-1530
Collins 51J4
Drake R4B*, R4C*
Swan 600R with 330 tuner
Collins R390A, R391
Heathkit SB313*
Drake SW4A
Galaxy R-530
Technical Materiel GPR92
Collins R388/51J3
Hammarlund HQ-180A
National WRR-2A
Collins R-390, R-392
Technical Materiel GPR90, GPR91
Collins R648/ARR41
Hallicrafters SX-122A
Hallicrafters SX73/R-274FRR
Hammarlund SP600JX
Hallicrafters SX88
National NC400
Hallicrafters SX112
*Allied SX190**
Hallicrafters SX100
Hallicrafters SX96
Hammarlund PRO-310
Yaesu FRG-7
Barlow-Wadley XCR-30
Zenith R-1484/PRR-15
Hammarlund HQ-180
Hammarlund HQ-160
Hammarlund HQ-150
National HR060, HR050
Hammarlund HQ140XA
R-441/SRR13A
Hammarlund HQ145A
Hallicrafters SX133
Drake SSR1
Trio-Kenwood QR666/R-300

LOW-COST RECEIVERS
Hammarlund HQ200
Lafayette HA-600A
National NC-183D
Radio Shack DX-150A
Heathkit GR-78
Radio Shack DX-150, DX-150B
Radio Shack DX-160

HIGH COST RECEIVERS (not in order)
Raytheon 1150 (Tempest)
Watkins-Johnson WJ-8940A
Signal One
Technical Materiel DDRR-10/FRR-85
Technical Materiel GPR-110
Drake DSR-2, DSR-1
Astro SR-502M
Collins 651S1
National HRO-600
Collins 51S1
*Collins 75S3**
Raytheon 1230A
ITT Mackay 3021A, 3020A
Communications Associates CR70
Eddystone 958, 1830
Harris Intertype RF505
Rohde and Schwartz EK-56
National HRO 500

NOTES: Asterisk receivers require additional crystals for general coverage. Italicized receivers are the most popular among listeners. All receivers will work on 120 volts AC, 60 Hz, except R-648 and R-392. All receivers require external speakers except SPR4, FRG-7, DX-150, GR-78, QR666, R-300, SSR-1, and XCR30.*

accessory equipment such as frequency counters or frequency meters are useful.

Additionally, resetability (retuning the dial back to an earlier setting and having it right on frequency) and backlash (lack of immediate response when slightly adjusting the tuning dial due to loose mechanics such as gear mesh, tension springs, worn shafts and bushings, loose vernier drive, and stretched dial cords) must be considered.

Internal crystal calibrators are found in many receivers providing calibration points, usually every 100 kHz or so, throughout the tuning range.

Modes of Detection. Standard AM envelope detection is universal on HF receivers; the BFO may be used for CW, RTTY, SSB, and FAX. Modern receivers have evolved from simple BFO circuitry through exalted BFO's to product detectors for SSB. Few modern HF receivers possess an FM mode due to the relative absence of FM signals below 30 MHz. FM detection is useful, however, when the receiver is intended for use with VHF/UHF converters.

Automatic Gain Control. In order to avoid RF-stage overload problems, a portion of the detected signal is rectified and fed back to the RF stages as bias; strong signals reduce the stage amplification. Rapid recovery is desirable when listening to conventional AM, but a "pumping" action occurs when listening to CW or SSB; therefore, slow AGC recovery is recommended for these modes. Many modern receivers provide selectable AGC response time; if not, it is advisable to manually reduce the RF gain on strong SSB and CW signals.

Signal-Strength Meters. The S-meters on most receivers show relative strength, not

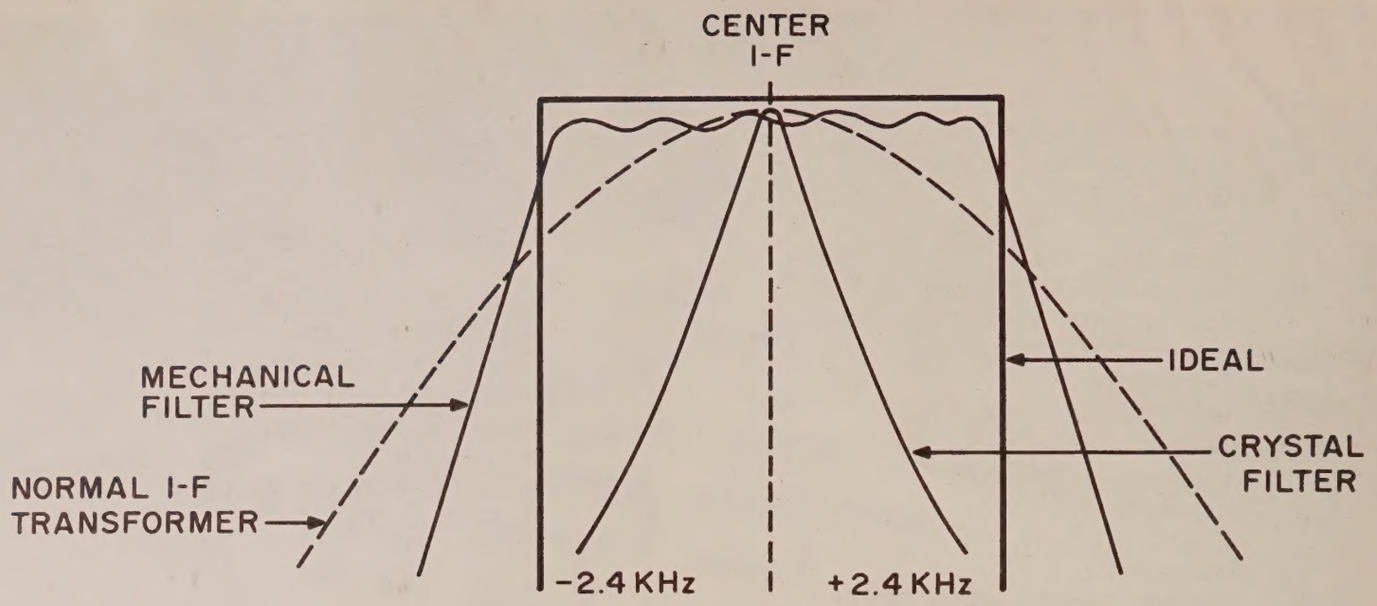


Fig. 4-6. Typical i-f filter techniques compared with ideal voice passband.

absolute magnitude, of incoming signals. Therefore, they are useful for tuning purposes and reference levels, but not for actual signal-level measurements. An S-meter should read full-scale on only the strongest signals.

Miscellaneous features such as rubber feet, large tuning knobs, and convenient control placement are additional considerations.

RECOMMENDED RECEIVERS

The new and used receivers in Table 4 are recommended for reliable and effective shortwave performance, see Fig. 4-7. Moderately priced and low-cost receivers are arranged *approximately* in decreasing order of preference as judged by the author. Not all models have been personally tested by the author; many factors are taken into consideration for relative order, including age, dial accuracy, mechanical construction, electrical performance, control flexibility, general reputation, and relative cost. It is generally not worth an additional investment to abandon a good receiver in order to acquire one only a step or two higher on the list; similarly, it is not advisable to replace a good receiver with one higher on the list, but in poor condition. Above all, examine all aspects of the prospective receiver before buying it; remember, there are individual differences in receivers of the same model, even when new!

There are many older military surplus receivers available which have enjoyed an enduring reputation for their rugged quality, such as BC-342, BC-348, R-42/ARR7, SP210LX/BC779, AR-88, and SX-28. Held in their proper perspective (ignoring time-worn reverance and nostalgia) none of these receivers can measure up to the performance of moderately-priced modern communications receivers. At the right price, some do make acceptable standby or secondary receivers (for duplex monitoring, for example). Update modifications may prove worthwhile to the inveterate experimenter.

RECONDITIONING A RECEIVER

Whether performance of a used receiver is suspect or not, a few straightforward steps will provide the new owner with ease of mind. The following procedure should be followed in order for practical, as well as electronic, reasons.

Remove the chassis from the cabinet. Dust should be brushed or vacuumed out (air pressure jets tend to blow particles into mechanics). Tighten all hardware. Remove the knobs and wash the panel with mild soap and water or ammonia; wipe-rinse with a damp cloth. Worn embossed panel lettering may be filled by rubbing with a lacquer paint stick. Be careful with solvents; they can ruin plastic and remove lettering. The cabinet may be similarly washed, and then spray painted with an inexpensive enamel aerosol if warranted. Ribbed knobs are easily cleaned with an old tooth brush.

Test all tubes, replacing as necessary; while tubes are out, lightly spray socket holes with aerosol contact cleaner from the top of the chassis. Wipe away excess cleaner. Don't forget to test *new* tubes before replacement!

In older receivers, routinely replace all coupling and bypass capacitors which have high voltage on one side only; they are probably leaky and will reduce performance. If in doubt, snip the low voltage lead from the capacitor loose from the circuit (power cord unplugged for safety!), leaving enough lead length to secure and re-solder the connection if the capacitor passes the following test. Using a high resistance ohmmeter (scale times 10,000 or higher), connect the prods across the capacitor leads; a momentary rise and fall of the needle when first connected is normal, but a sustained reading of less than several megohms indicates leakage. Electrolytic capacitors will show greater leakage, often as low as 100,000 Ohms or so; this is normal.

An alternative test may be performed with the set turned *on.* With the low voltage lead of the capacitor disconnected as before (with the power disconnected), and a sensitive voltmeter *carefully* connected between the loose lead and the chassis, look for a deflection on the meter with power on. Any sustained reading indicates a leaky capacitor which should be replaced (with the power once again disconnected). Epoxy-dipped mylar capacitors are excellent economical choices for general purpose audio and IF applications in

the .001-.5 uF range; mica capacitors are a better choice for RF, oscillator, and mixer applications in the 10-1000 picofarad range. Observe temperature coefficients when replacing oscillator capacitors! Leads should be cut as short as practical.

Carbon composition resistors also change value with age; they are best checked in-circuit, measuring operational voltages with a vacuum tube or transistorized voltmeter. Look for charred, bubbled, or cracked resistors and replace them routinely.

Solvent-clean and lubricate gears, shaft bushings, bearings and gliding surfaces. Never abrasive-clean plated connectors; use recommended solvents. Spray contact cleaner on and into all electrical contact surfaces: switches, potentiometers, and tuning-capacitor wipers. *Do not* get chemicals on components, especially in the oscillator stage; drift will be aggravated.

Align the entire receiver as specified in the manual; the general order (if not specified) is IF, RF, mixer, and oscillator stages, from lowest to highest frequency ranges. The antenna circuits should be adjusted with the antenna connected to the receiver, and tuned for maximum signal strength on a weak station or background noise. In all alignments, adjust slug coils at the low frequency end of a band range, and trimmer capacitors at the high frequency end.

Tube Substitution. Front-end tube substitution is unpredictable at best. The manufacturer knew what he was doing (usually) when he designed the RF stages of your receiver, but it is possible that other tubes might provide better performance. High-gain, low-noise tubes are popular replacements. If you have access to a large tube collection containing industrial and surplus varieties, you might try interchanging

Fig. 4-7. The SPR-4 and DSR-2, outstanding performers among general coverage receivers. (Courtesy Drake.)

tubes, see Table 5.

After making a substitution, test the receiver's performance on both weak and strong signals; blocking can occur with sharp-cutoff tubes on strong signals. Remote-cutoff tubes are preferred in RF service for lower cross modulation and intermodulation distortion.

Naturally, other replacements are possible, but check a tube manual for matching base diagrams first, or receiver damage may easily occur. If a substitute tube has electrical characteristics different from the original, realignment of that stage will probably be necessary.

Many articles on conversion of tube stages have been published in amateur radio magazines.

Table 5.

Tube	*Substitutes*
6AG5	6BC5, 6AK5, 6CY5
6AU6	6BA6, 6CB6, 6BH6, 6BZ6, 6BJ6, 6AH6, 6DC6, 6DE6, 6DK6, 6HQ6, 6136, 6661, 7543
6BE6	5750, 5915A, 7036, 7502, 6BY6, 6CS6
6BQ7	6BK7, 6BZ7
6SK7	6SS7, 6AC7/1852, 6AB7/1853, 717A, 6SG7, 6SH7
6U8	6EA8

VLF RECEIVERS AND CONVERTERS

Traditionally, VLF receiving equipment has employed large RF coils and tuning capacitors for high-Q selectivity. With the advent of integrated-circuit operational amplifiers, miniature high-Q stages are now practical. Direct-conversion "synchrodyne" receivers are also effective in this portion of the spectrum.

Unfortunately, because of the minor consumer-hobby interest in frequencies below the AM broadcast band, there is no widescale manufacture of low-priced VLF receivers in the U.S. at this time. Some multiband radios include the 150-400 kHz European broadcast band (which also includes the aeronautical beacon weather band). Laboratory-quality fixed frequency 20 and 60 kHz time signal receivers are also available, as well as the 1-600 kHz tuneable RA-01 receiver from Bayshore Systems. Additionally, many high-cost spectrum analyzing receivers cover this low frequency range. But for the casual listener who desires a low-cost general coverage VLF receiver, the prospect is dismal indeed! A limited number of early vintage marine and military receivers (RAK, RAO, RBH, RBL, BC-969A, etc.) occasionally surface on the used equipment market, as well as the later high quality Collins R389, Hammarlund SP600VLF, and RCA AN/SRR-11.

An alternative and highly effective approach is the construction of a fixed frequency converter, using a communications receiver as a tuneable IF system. By selecting an IF of 3.5 MHz for example, any receiver with 80 meter coverage may be employed as a tuneable IF system; better yet, if the receiver has 500 kHz increments as so many SSB amateur receivers and transceivers have, direct readout dial accuracy from 0-500 kHz is possible. An antenna-matching preselector on the converter front end controls its selectivity and sensitivity.

Both power line interference and atmospheric noise are severe in the VLF and LF region; late-night reception is the general rule. Power line isolation is often accomplished by using battery operated receivers.

VHF/UHF RECEIVERS AND CONVERTERS

With very few exceptions (e.g., Hammarlund SP600 and Hallicrafters SX73/R274FRR), the popular general coverage shortwave receiver stops at the beginning of the VHF range. In the VHF and UHF portion of the radio spectrum, land mobile services are in the FM mode, while aeronautical communications are still AM. Many excellent military surplus 220-400 MHz UHF aeronautical AM receivers are readily available on the used market, such as the National URR-13, URR-35, and Collins R278/GRC (all tuneable); commercial surplus VHF/UHF receivers and transceivers are crystal controlled.

Unlike VLF, an enormous number of tuneable and fixed frequency consumer grade receivers are readily available, especially the hand-held variety, see Fig. 4-8. Simple single conversion, multiband plastic cabinet portable radios are woefully inadequate in virtually all specifications:

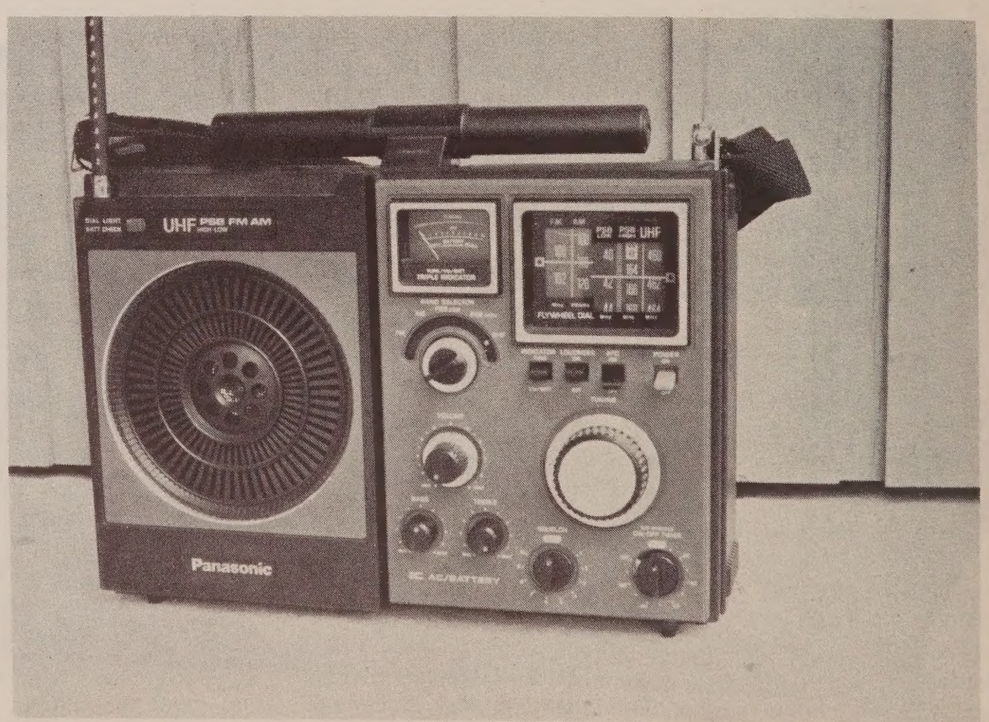


Fig. 4-8. Multiband portable radios are handy and cute, but definitely not of communications quality.

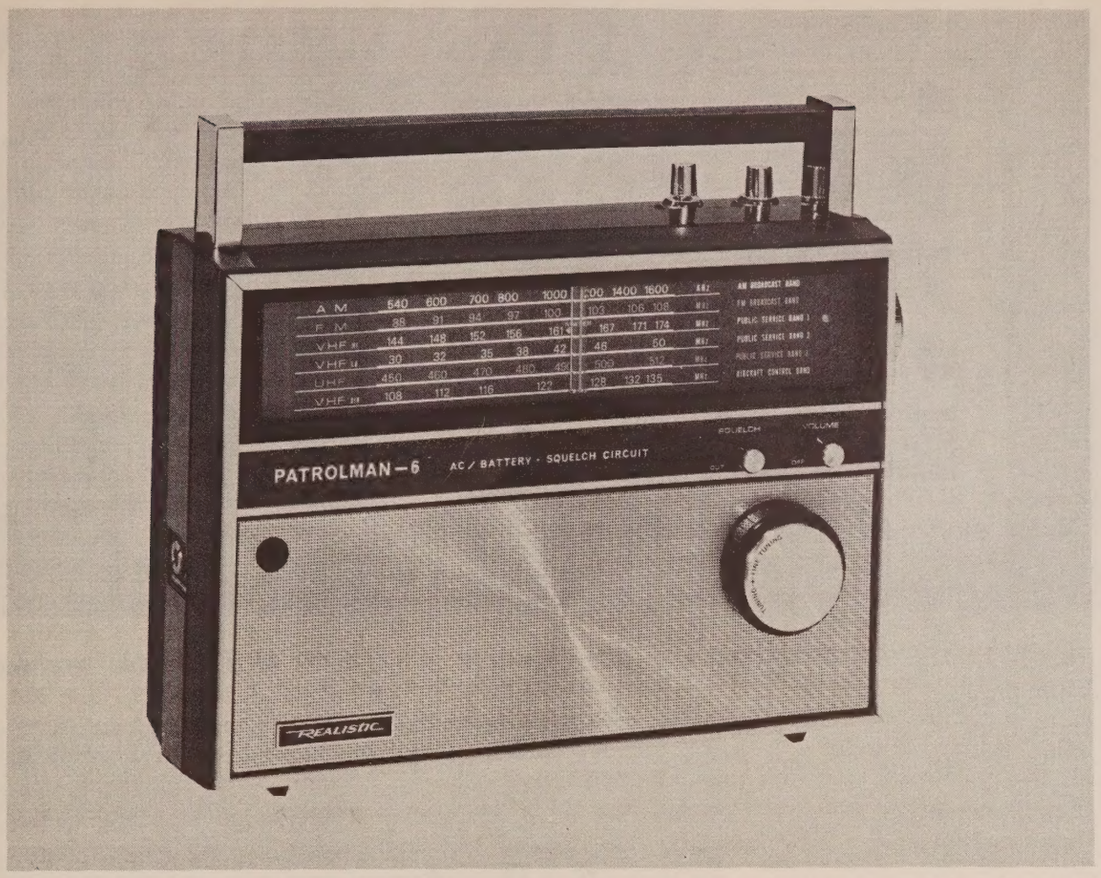


Fig. 4-9. Radio Shack's Patrolman 6 is an unusually good performer for a multiband portable radio.

sensitivity, RF and IF selectivity, intermodulation, image rejection, noise factor, AM rejection, calibration, and squelch threshold. Oscillator instability is camouflaged by automatic frequency control diodes. Their advantages are portability and frequency coverage. A very few tuneable VHF/UHF portable radios give surprisingly good performance for their low cost, such as Radio Shack's Patrolman 6, see Fig. 4-9.

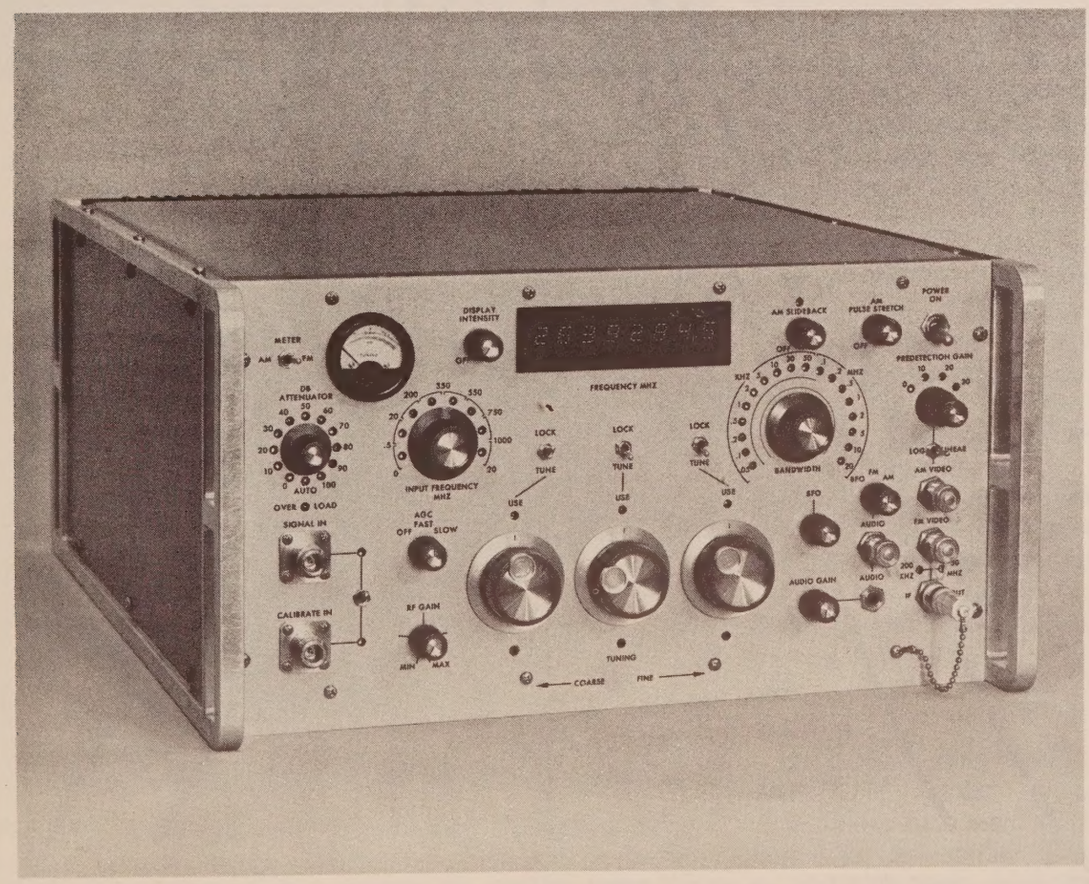


Fig. 4-10. Raytheon's 1150 Tempest receiver is custom made to order.

Better receivers for the consumer have been made from time to time, including Radio Shack's PRO-3A and Lafayette's PF-300, but at this writing the market is devoid of hobby-priced communications-quality tuneable VHF/UHF receivers.

The cost of high quality tuneable receivers normally restricts their use to professional, commercial, governmental, and institutional applications, such as those receivers available from Astro Communications. Occasionally, some of these become available on the surplus market, including those made by Nems-Clarke (1306 and 1907), CEI/Watkins-Johnson (903, 905, and 960), LTV/TEMCO (G175), Eddystone-Marconi (990R, 990S, 1990R), and Airborne Instruments (R-1283/GRC). See Fig. 4-10.

Earlier models of telemetry and electronic countermeasures (ECM) receivers are well designed, but their wide bandwidths and instability make them poor choices for monitoring modern narrowband (5-10 kHz deviation) FM communications. Their omission of squelch also inflicts irritating and fatiguing background noise during periods of no signal monitoring. These include R444, APR4, APR4Y (R555) with CV253 tuner and R593.

By the time VHF was becoming popularized in the 1940's, two manufacturers, National and Hallicrafters, were producing receivers which extended into the VHF range. At that time, VHF communications were mostly experimental AM, and the bands were not crowded; these used receivers are not capable of acceptable performance by today's standards.

In a desperate search for modern, commercially made VHF/UHF receiving equipment at a reasonable price, the prospective listener is tempted to buy test equipment, such as field-strength meters, spectrum analyzers, noise interference locators, and service monitors. Al-

though of individual merit, their performance as general coverage VHF/UHF receivers lacks in one or more of the specifications listed under multiband portable radios. Regency's AM/FM-1000A probably comes closest to standing alone as a flexible receiver, but its cost is discouraging to all except serious users. (Fig. 4-11.) Similarly, Cushman's CE-15 is an excellent, but expensive, receiver/spectrum analyzer.

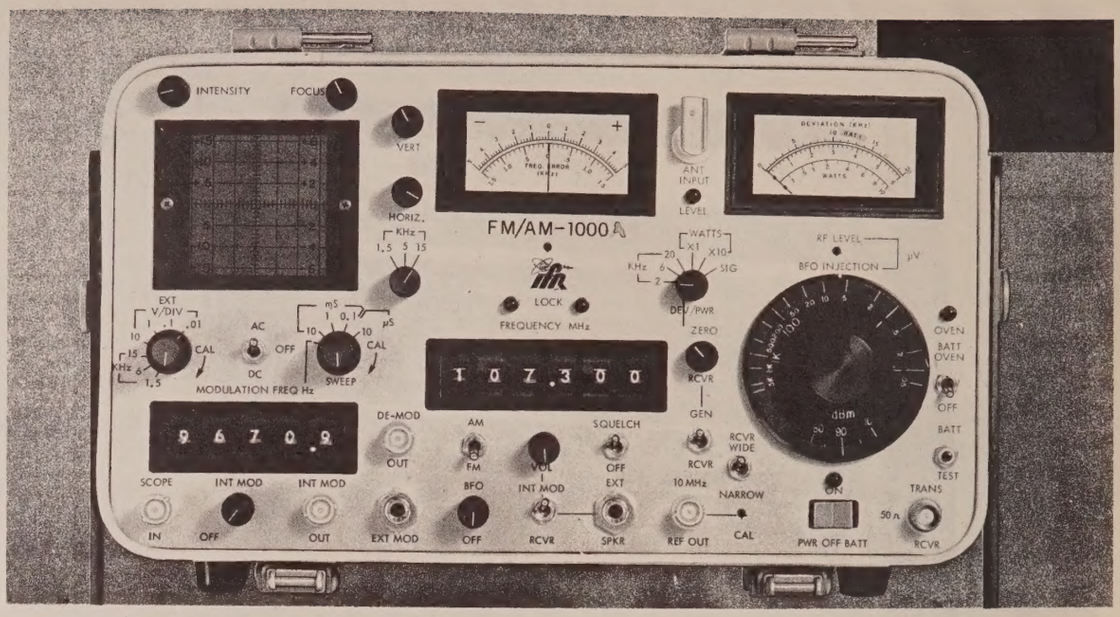


Fig. 4-11. The FM/AM-1000A from Regency/IFR is a 1-1000 MHz portable receiving laboratory.

Converters

Most of the limitations cited above are overcome by the use of well designed converters operating into good quality receivers. Unless the receiver has an FM detector however, FM signals will have to be "slope-detected" (delta demodulation). See Fig. 4-12. The AM receiver is tuned slightly to one side of the FM center carrier, and modulation is detected as conventional AM as the modulated carrier sweeps across the receiver passband. Naturally, the noise immune advantage of FM cannot be realized by this technique, but detected audio is very intelligible, and the noise limiter of the receiver can always be called into use if pulse noise is a problem.

There are many high quality, low cost converters and preamplifiers available on the market today, both assembled and in kit form. Generally, they are limited to narrow frequency ranges; for general coverage, multiple converters or coil switching will have to be employed.

A frequency counter prescaler may not be used as a frequency down-converter for modulated signals; although a divide-by-10 prescaler will digitally convert a 160 MHz VHF signal to 16 MHz, it also divides the FM deviation by ten, making it undetectable. AM is automatically clipped by the digital nature of the circuitry.

A UHF tuner from a discarded TV set may be called into service as a UHF con-

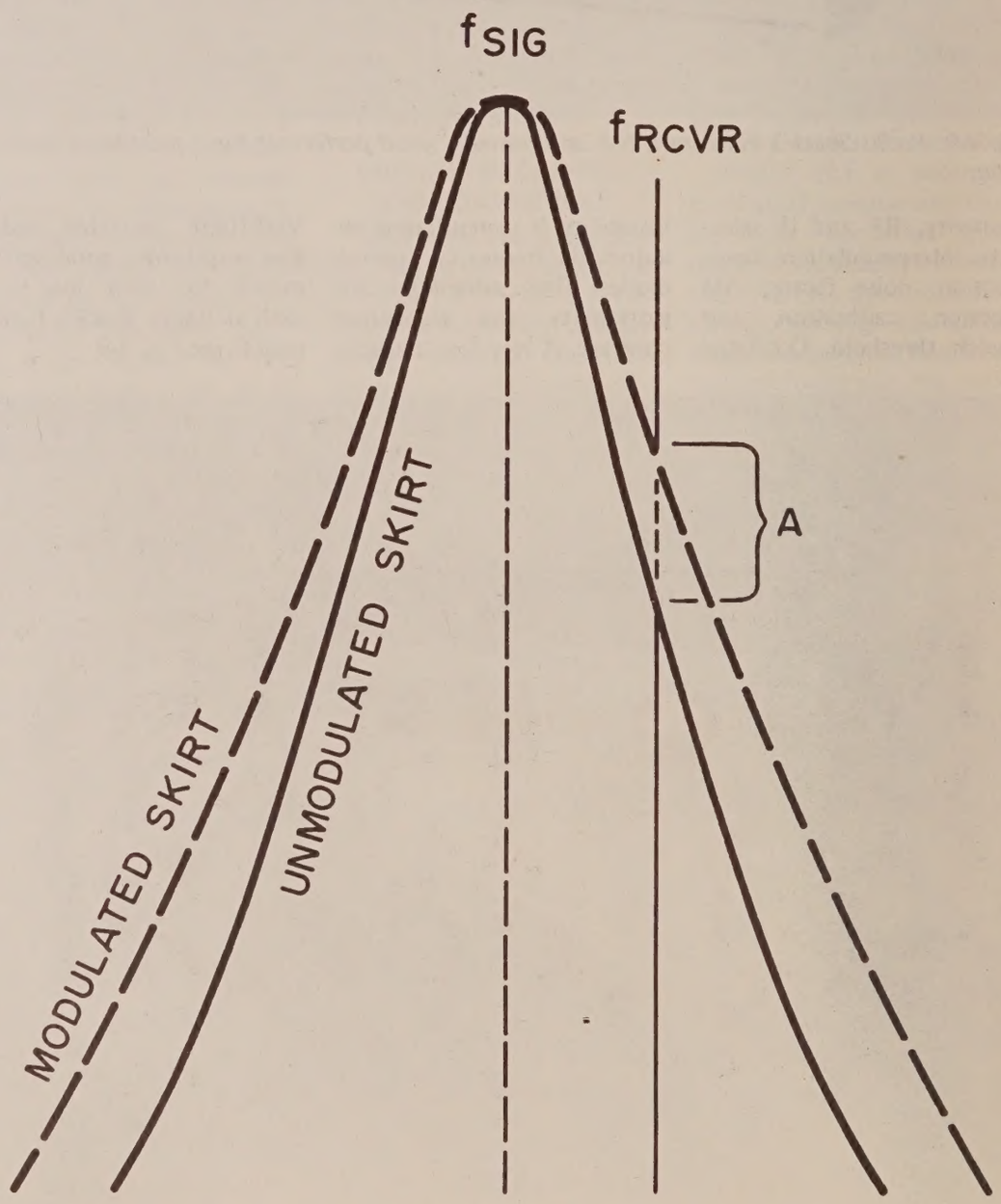
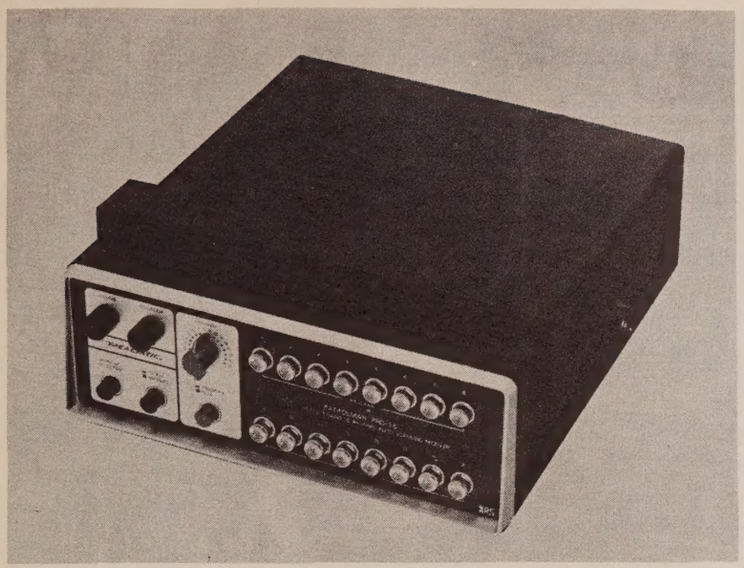
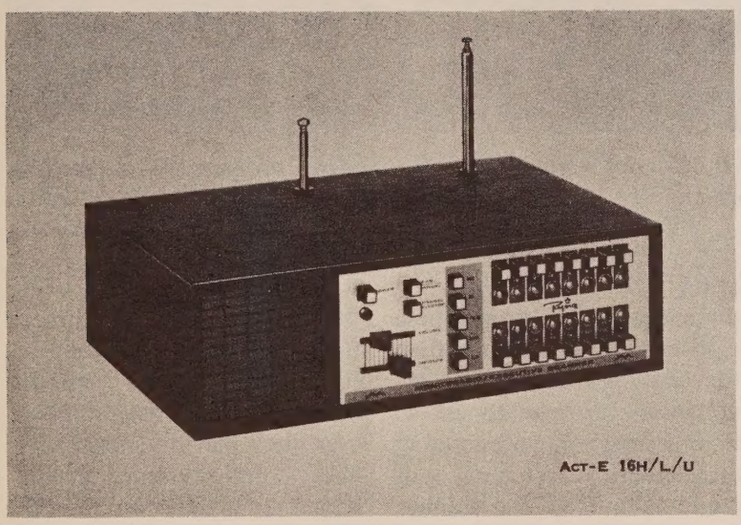


Fig. 4-12. Slope detection: as an FM signal deviates horizontally with modulation (f-sig), the off-set AM receiver passband (f-rcvr) sees an apparent change in vertical amplitude (A).





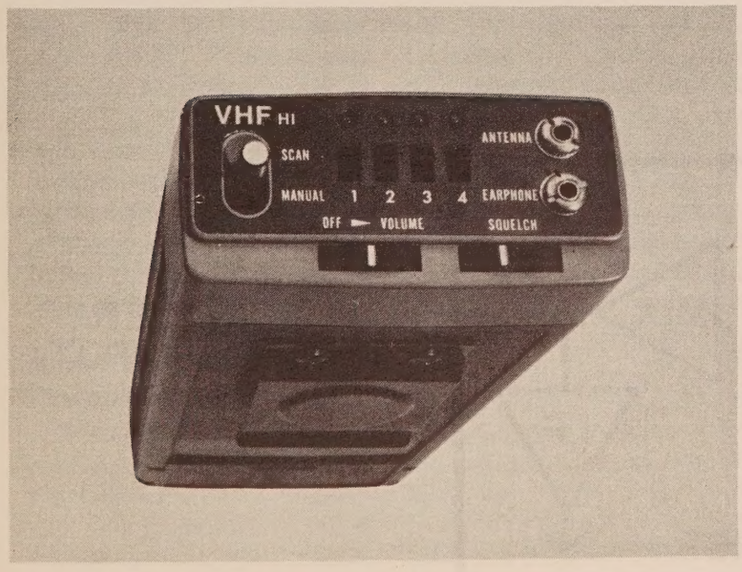


Fig. 4-13. VHF and UHF scanners may be mobile, base or pocket-portable varieties: shown are from top to bottom, Radio Shack's PRO-16, Regency's ACT-E 16H/L/U, and Radio Shack's PRO-4A.

verter of sorts in an emergency; unmodified, it will have a sensitivity of 5-10 microvolts, and very broad RF selectivity, encouraging images. Designed for 470-890 MHz operation, it may be padded down to receive 400-500 MHz, or slightly detuned higher to receive the recently added 900 MHz land-mobile band. Alternatively, because its IF output is so broadband, it may tune the 450-512 MHz band merely by feeding the output into a receiver tuned 20 MHz lower than the original design frequency (20 MHz instead of 42 MHz). The HF receiver is then tuned as a variable IF system, while the tuning range is selected by the UHF converter. Similarly, an add-on UHF TV converter, available from several mail-order jobbers, may be called into service the same way. Generally, it is designed to work into channel two (54 MHz), so it may be connected into the antenna input of an HF receiver at about 30 MHz and FM stations slope-detected, or it may feed its output directly into a 30 MHz low-band FM monitor.

It must be emphasized that neither the TV tuner or UHF converter is designed to provide communications performance; their use is mentioned merely for thoroughness.

Some manufacturers offer a wide selection of modular kits for those experimenters who prefer building their own VHF/UHF receivers; for those individuals with time and talent, these products are very well engineered.

An additional refinement would be the addition of a digital frequency synthesizer to control the oscillator frequency, providing a high order of dial readout accuracy.

Scanners

Since the early 1970's, VHF/UHF public service monitoring has been dominated by the scanner (Fig. 4-13), a crystal controlled high quality FM receiver whose multiple oscillators sequentially scan their preset operating frequencies until a carrier is detected, tripping the squelch circuit and locking the oscillator on that channel. After the carrier disappears, the scanning circuitry takes over again. A priority channel is usually provided assuring the listener that he will hear that channel when it becomes active regardless of the channel position of the scanner.

Scanners come in all varieties: pocket-size, portable, mobile, and fixed-base; they may be 4 channel to 16 channel or more, single or multiband.

Without question, one of the most important recent improvements in communications monitoring is programmable memory (Fig. 4-14); blending crystal synthesis and digital memory technology, the operator may choose at random any of thousands of possible channels and enter the program into the scanner. Several variations are used to accomplish this, including optically-encoded cards (SBE), push-button encoding and digital readout (Bearcat 210), and binary-encoded programming (Bearcat 101/101A). The number of possible selections is limited by design parameters which include incremental crystal heterodyning products (designed for 5, 10, or 12.5 kHz channel spacing) and front-end passband (usually voltage tuned by varactor diodes).

Advantages of push-button programmable memory, over replaceable crystals are substantial and include no additional cost for crystal replacement, instant reprogramming without waiting for new crystals, convenient front-panel programming, and incremental selection of any crystal stable frequency allocation in the receiver's passband at a moment's notice.

Additionally, programmable memory offers another important flexibility: by coupling the scanner's mixer output to the antenna input

of a general coverage shortwave receiver, a completely programmable tuneable VHF/UHF option becomes available for frequency surveillance (Fig. 4-15). In this scheme, the scanner acts as a converter, and the HF receiver becomes a slope-detecting tuneable IF system, capable of tuning several megahertz either side of the converter channel; it also permits tuning above and below the programmable limits of the scanner. The center frequency may be chosen at will depending upon the programming of the scanner (naturally, a conventional crystal controlled scanner may be used in this same manner, as may any converter, limited only by the selection of crystals).

By setting the scanner on a frequency of interest, and then using the HF receiver in a search mode, simultaneous 2-frequency reception is effected as the scanner continues to operate normally.

Another benefit from this combination is the ability to detect SSB, AM, CW, and RTTY signals occasionally encountered in the VHF/UHF range.

A high order of dial accuracy is possible with this system if the HF receiver is one of many available with dial calibration of one kilohertz or better. But first, the exact intermediate frequency output of the scanner's mixer must be determined (Fig. 4-16). This may be readily calculated by setting the scanner to receive a carrier of known operating frequency; the HF receiver (BFO on) is then tuned to the scanner IF (usually near 10.7 or 10.8 MHz) and adjusted for zero-beat. By tuning the HF receiver higher or lower in frequency, other VHF or UHF signals will be heard, displaced from the original carrier frequency by the same amount as tuned by the HF receiver dial. For example, if a National Weather Service station broadcast is selected at 162.55 MHz, and the tuneable HF receiver zero-beat this IF signal at 10.705 MHz, then another signal heard at 11.705 MHz must be exactly 1 MHz away from the 162.55 MHz station. It must be remembered, however, that frequencies *above* the IF will be *lower* than the original carrier. Thus, our imaginary 11.705 MHz station is operating on 161.55 MHz; a pocket calculator makes these calculations a breeze. When determining your scanner IF, it would be wise to do so with several known operating frequencies, averaging out errors. Don't set the scanner on a strong station or the AGC circuit may lower the sensitivity of the entire tuning range.

There are technical limitations to the effectiveness of such a broadband system; images may be severe, however they can be spotted by their rapid-tuning characteristics: they seem to pass by the dial faster than other carriers (in fact, they do because their frequencies change as

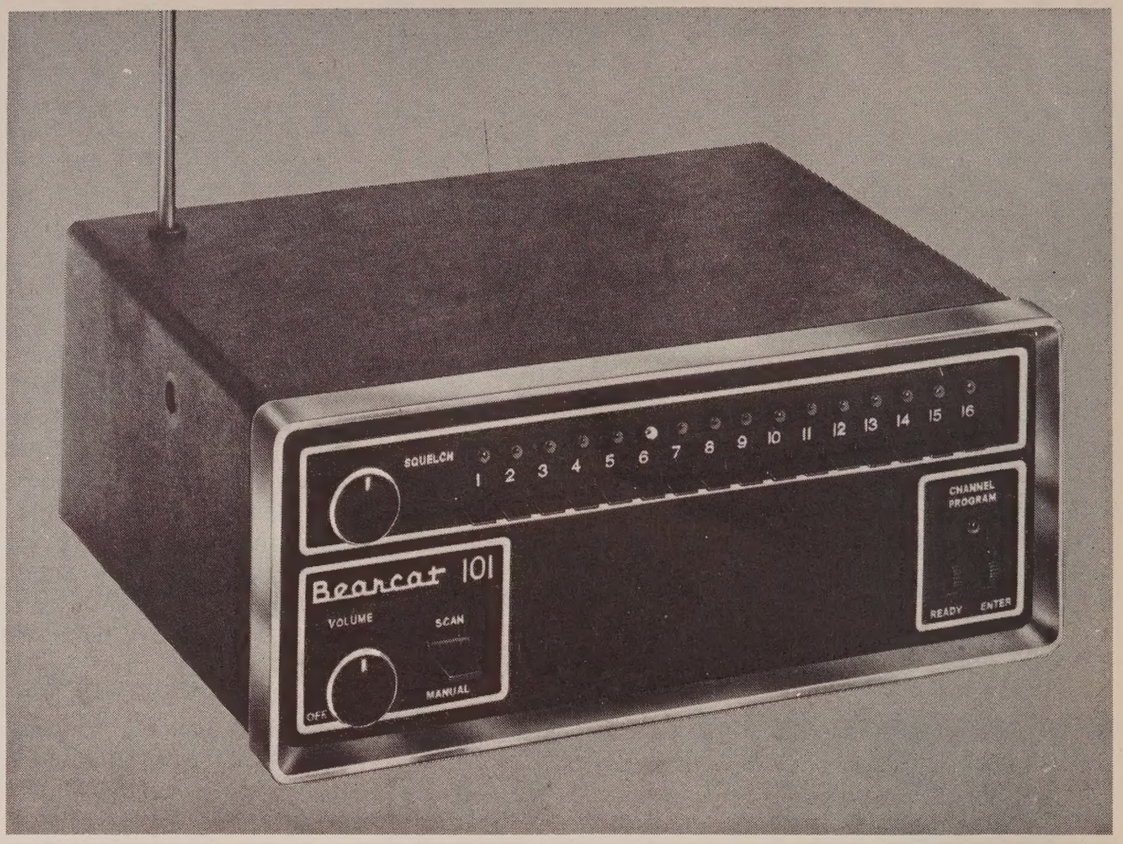


Fig. 4-14. Electra's BC-101 and BC-101A (includes 400-490 MHz) programmable-synthesis VHF/UHF scanner is a hot performer.

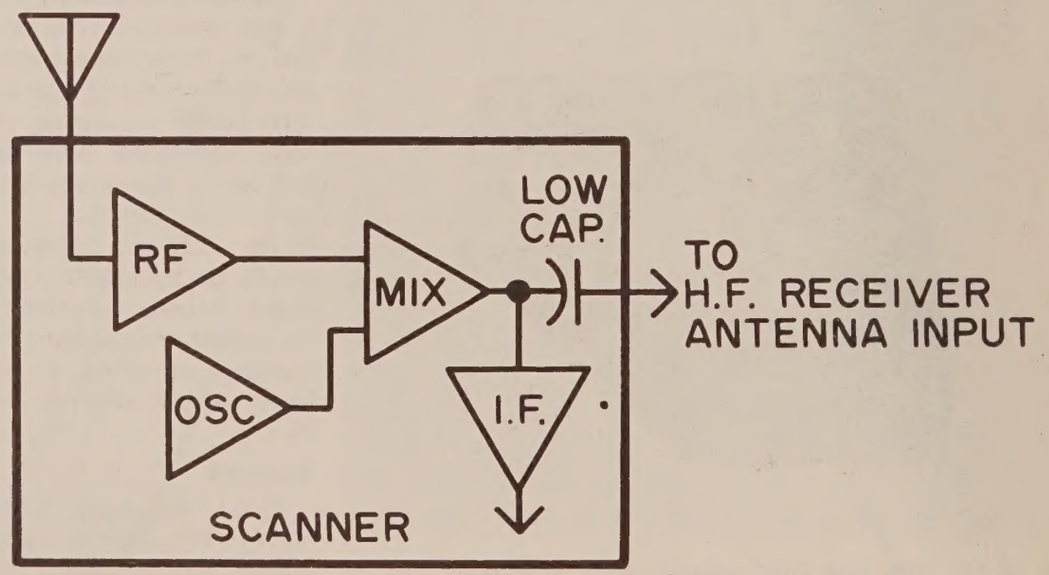
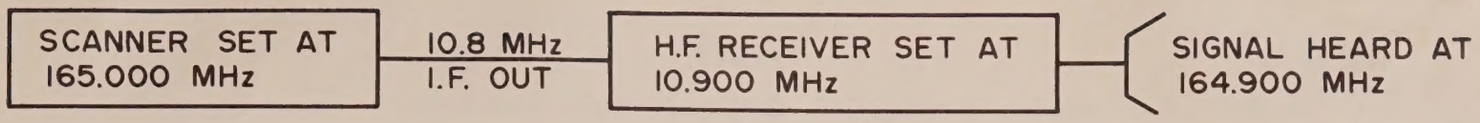


Fig. 4-15. Connecting the scanner's mixer output to an HF receiver to be used as a tuneable IF system.



f SIGNAL = f SCANNER ± H.F. DIAL DISPLACEMENT FROM I-F (+DOWN, -UP IN FREQ)

Fig. 4-16. Using the known i-f frequency of the scanner to determine the frequency of an intercepted VHF or UHF station by reading the dial of the HF receiver.

the receiver oscillator is changed, and in the opposite direction!).

Some spurious signals may be recognized by a ragged, distorted "overmodulation" sound; other "spurs" are characterized as two voices appearing simultaneously on one signal, often disappearing entirely in the middle of a sentence. This is due to the mixing of two signal frequencies producing a third (or even more) to which you are tuned; when one carrier shuts off, the mixing disappears and the spur is gone.

A panoramic adaptor may be of great service in helping to identify these phantom signals produced by random mixing the broadband RF system. Of course, all of these shortcomings may be attenuated through the use of selective RF circuitry, or by the addition of an antenna preselector or filter, thus narrowing the passband of the system.

To make dial interpolation easier, after you have determined the IF of your scanner by zero beating a signal of known operating frequency with your HF receiver, adjust the receiver "dial-set" or hairline centering to a nearby reference point; it is easier to subtract or add 10.7 (or even 10 or 11) than 11.798!

Modern VHF/UHF Receiver Design Parameters

Whether walkie-talkie or base station, crystal control is the rule in today's commercial and governmental land-mobile services. An explosive growth in the recently allocated 900 MHz band is certain; frequency stability is .0002% (2 parts per million). Adjacent channel selectivity is upwards of 100 dB, with sensitivity on the order of .25 microvolt. Standard FM deviation is ±7 kHz, and spurious responses are down 100 dB.

Multiple front-end field effect transistors tuned by cavity filters provide intermodulation rejection of 80 dB; more is possible with crystal filters. Options include data display, hard-copy printout, selective calling, and voice scrambling. Naturally, geometric tolerances become highly critical at these high frequencies.

LISTENING TECHNIQUES

Random spinning of the tuning knob on a receiver as an effort to locate unknown stations may be compared to firing a gun repeatedly into a fog in hopes of hitting a duck! To make the assignment easier and far more productive, certain accessory equipment and monitoring procedures should be considered for implementation in the monitoring station. Listening efficiency is markedly improved if certain considerations are taken into account; these include: (1) Propagation conditions; (2) Maximum useable frequency (MUF); (3) Transmission schedules; (4) Time zones. All of these factors come into sharp focus if we consider a worst-case example: attempting to monitor from the United States a utility office located in England on 30 MHz at 2 AM their local time! The office is closed, MUF is well below 30 MHz at that time, propagation between the U.S. and the British Isles is dismal at that frequency and time; and even if all these factors were favorable, perhaps their schedule of transmissions from that office is not during *your* chosen listening period. A few well-thought-out practices will insure greater listening success.

A feeling for band openings may be secured by casual tuning of the frequency band of interest while asking yourself is the band crowded with signals? Are they strong? Are the signals stable or fading in and out? From what geographical regions are the signals coming? What is the background noise level? A list of international broadcast stations and operating schedules will enable the listener to better predict the likelihood of monitoring a station of interest in the same general location on an adjacent frequency; strong, stable reception of the broadcast station is a good indicator of favorable propagation between you and the region of interest.

Propagation forecasts are available from periodicals (73 magazine), broadcasts (WWV, Ft. Collins, CO), and radio services (Voice of America). International broadcasting schedules and frequencies are available from a wide array of sources, including publications such as the World Radio-TV Handbook, the Short-Wave Listener's Guide by H. Charles Woodruff (Radio Shack), International Radio Club of America Foreign Log (6059 Essex St., Riverside CA 92504), and White's Radio Log (published variously as a supplement to popular radio magazines).

Small computers may be programmed for optimum correlations of sunspot activity, sidereal time, wavelength, and propagation path. The advent of microprocessors affords the experimenter the option of designing his own computer circuitry for custom programming.

Local monitoring stations can easily co-ordinate their efforts, thus maximizing their listening effectiveness; friendly competition also encourages proficiency!

Logging. Effective logging of stations of interest makes later identification easier. A recommended log sheet and fictional entry might appear as in Chart 1.

The SINPO code is a qualitative evaluation of a received signal, and is assessed in Chart 2. An analysis of a previous report which has this much detail should help in formulating a later attempt to receive similar signals.

Predetection recording. One of the most sophisticated systems for surveillance and detection of radio signals is provided by wide-band video (RF) recording techniques. A portion of the radio spectrum is recorded in real time, right off the antenna system; the tape recorder may be unattended. The resulting recording may be played back at will, as often as desired, feeding a spectrum analyzer for signal recognition and analysis, or a receiver for tuning and monitoring.

Professional helical-scan color video tape recorders are capable of continuous recording from VLF well into the HF spectrum; higher frequencies are down-converted by conventional techniques and recorded at lower frequencies. Surplus video tape

Chart 1.

Frequency	*Mode*	*Callsign/I.D.*	*Service*	*Location*	*Signal (SINPO)*	*Time/Day/Date*	*Traffic/Comments*
11243 kHz	A3J	Looking Glass	SAC	N.Y.	44354	1430Z Tues 1/7/76	"E.T.A. 1450Z"

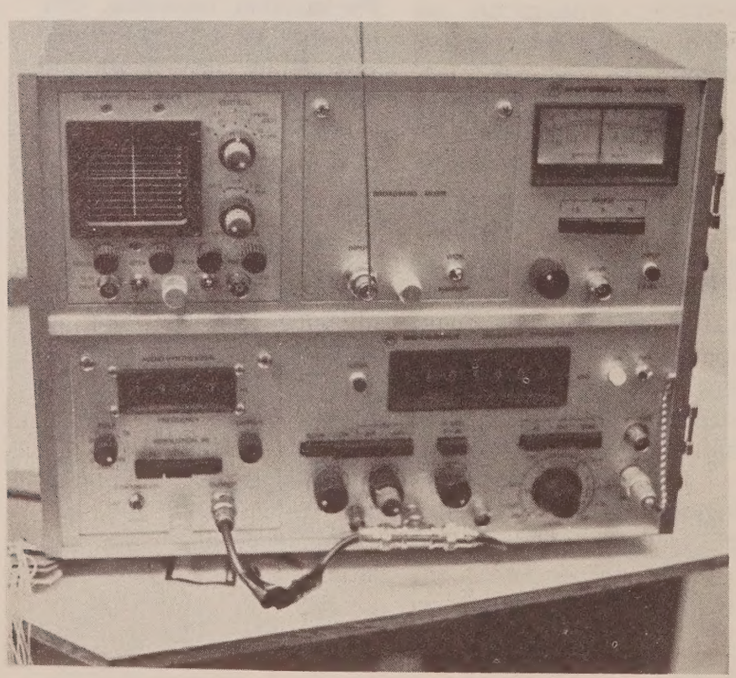


Fig. 4-17. Service monitors are generally too specialized to justify their expense as VHF/UHF receivers. Seen here are Singer's signal monitor, Motorola's service monitor (.01 Hz-1000 MHz), and Sushman's CE-6 service monitor. Additionally, their sensitivities are low because they are designed to analyze an adjacent transmitter under maintenance. Similar limitations also apply to spectrum analyzers.

Chart 2.

Signal Strength	*Interference*	*Atmospheric Noise*	*Propagation Disturbance*	*Overall Merit*
5 Excellent	5 None	5 None	5 None	5 Excellent
4 Good	4 Slight	4 Slight	4 Slight	4 Good
3 Fair	3 Moderate	3 Moderate	3 Moderate	3 Fair
2 Poor	2 Severe	2 Severe	2 Severe	2 Poor
1 Barely audible	1 Extreme	1 Extreme	1 Extreme	1 Unusable

recorders are available at low cost.

Predetection recording is widely used by government intelligence agencies and NASA.

Panoramic receivers and panoramic adaptors. Feeding from the IF system (generally off the mixer for greatest display bandwidth), these cathode-ray displays are excellent accessories for observing and analyzing radio signal activity not only on the frequency to which the receiver is tuned, but also considerably off-frequency.

Spectrum analyzers. These extremely wide-band devices are designed to provide graphic representation of spectrum use and are often over 1000 MHz wide, see Fig. 4-17. They are not effective monitoring receivers, as selectivity and modulation detection are unnecessary in such applications. They are useful, but very expensive, accessories in a monitoring station.

RECEIVING ACCESSORIES

Speakers and headphones. Although a single speaker could be switched between receivers, simultaneous monitoring of more than one receiver is frequently desirable; using one speaker for more than one receiver is confusing, which increases listener fatigue. For that reason, it is recommended that separate speakers be used. High-fidelity speakers should be avoided; their response to bass and treble frequencies contributes noise to the narrow passband of communications audio. Three or four inch general-replacement speakers installed in very small, internally-padded enclosures are preferred. Impedance is almost universally four or eight Ohms, a slight low-impedance mismatch of a few Ohms is insignificant, however many commercial receivers utilize 500 or 600 Ohm line outputs which will require a matching transformer.

A pair of cushioned headphones or stethoscopic earphones is a useful accessory for concerted listening without ambient distractions.

Filters. Few receivers possess audio-passband adjustment flexibility; several companies now offer active-filter audio processors which may be inserted between the receiver audio output and the speaker to custom-tailor the audio. These are advertised in amateur radio publications such as *73 magazine*. Peak/notch filters with adjustable bandwidth are especially attractive for this application. They may be trimmed to enhance CW/RTTY, voice, FAX, or any other characteristic audio by selective enhancing or nulling of discrete frequencies or bandwidths.

Panoramic adaptors. The visual display of a portion of the radio spectrum is very useful for off-frequency signal detection, signal-mode identification, noise-level reference, propagation-stability indication, and other applications as well. For wideband display, the panoramic adaptor should be connected at the mixer output, just before the receiver's first IF stage. Many communications receivers have IF outputs after several IF stages, limiting bandwidth and requiring a circuit modification if broadband display is desired. Low-capacitance (a few picofarads) coupling minimizes receiver loading or detuning.

Several models of panoramic analyzers are presently available, new and used; the Heathkit SB-620 is an excellent choice in a low-cost

Fig. 4-18. The author's receiving position (from left to right): HAL video RTTY display, Collins 51J4 receiver, Electra BC-101A scanner, and Heathkit SB-620 panadaptor. A 24 hour digital clock and reference manuals are conveniently placed above the table and the walls are covered with sound absorbing shag run remnants.

unit with a wide choice of input frequencies. Be sure the panadaptor you buy can correctly match the IF of your receiver.

Calibrator. If your receiver does not have internal calibration, a crystal calibrator is a necessary investment. Many have selectable increments, such as 1 MHz, 100 kHz, etc., with harmonics detectable through the VHF spectrum and higher. They may be mounted inside the receiver, or capacity-coupled externally to the antenna input.

Regular calibration checks are important, adjusting the calibrator trimmer against WWV or some other frequency of known accuracy; use the highest frequency practical to reduce calibration error when used on harmonics.

Signal generators and frequency counters. Aside from their uses in alignment, a stable signal generator may be used in conjunction with a frequency counter to determine received frequencies by the heterodyne method. The frequency counter should provide at least 7 digits $\pm$one count, and .0001% accuracy from an internal quartz clock for stability. Sensitivity should be 100 millivolts or better.

The received signal is zero-beat by the signal generator, the output of which is fed into a frequency counter to display accurately the frequency of the generator; keeping in mind that there is at least 5 or 10 kHz channel separation between frequency allocations in the VHF&UHF spectrum, an observed carrier frequency is easy to measure. For VHF/UHF applications, the signal generator RF is held within the frequency limits of the counter, and a harmonic of the generator is used to heterodyne the signal carrier. The upper-frequency limits of any frequency counter may be extended by the use of a prescaler. There are many stable commercial and military surplus signal generators with good stability, including BC-221, LM, USM32A, URM25, URM26, LM-105, and Measurements Model 80. Cheap hobby-type RF signal generators are generally inadequate for reliable measurements.

A frequency counter may also be used directly as a frequency readout, but it must be fed from an additional mixer to account for the IF displacement of the oscillator setting. In either case, accuracy of readout will depend upon the accuracy of the reference oscillator and number of readout digits. Some manufacturers provide frequency counters with built-in mixer for receiver I.F. offset indication.

With the astronomical number of integrated circuits now on the market, the era of low-cost digital-display test equipment has fully arrived. Many manufacturers now provide reasonably-priced frequency counters with useable accuracy. Some include provisions on the circuit board for the addition of a temperature-compensated crystal oscillator or oven. A casual glance through the display ads of various amateur radio magazines will provide a large selection of sources for inexpensive counters, as well as other test equipment.

Tape recorder. A cassette or reel-to-reel tape recorder is a valuable tool for signal identification; voice actuation (VOX) is helpful, but not essential. It may be used to record voice transmissions which are then replayed through an audio processor for enhanced intelligibility (as is done with surveillance recording). High-speed CW signals may be recorded and played back at a slower speed for copying. Tape recordings may also provide "living logs" for later reference, including RTTY and FAX printout, but remember the FCC prohibition against divulging or personally using any intercepted message!

REFERENCES

Receivers:
Understanding and Using Radio Communications Receivers by John Schultz (TAB 614)
The Radio Amateur's Handbook (ARRL, Newington, CN 06111)
Radio Communications Handbook (Radio Society of Great Britain)
Radio Handbook by William I. Orr (Editors and Engineers)

Sources for Surplus Receivers:
Slep Electronics, PO Box 100, Otto NC 28763
Fair Radio Sales, 1016 E. Eureka St., PO Box 1105, Lima OH 45802
Col. Wayne D. Russell, 9410 Walhampton, Louisville KY 40222
D and R Electronics, RD #1, Box 56, Milton PA 17847

Sources for Surplus Equipment Manuals:
Sam Consalvo W3IHD, 7218 Roanne Drive, Washington DC 20021
Quaker Electronics, Hunlock Creek PA 18621
Van's Electronics, 302 Passaic Avenue, Stirling NJ 07980
BVE Electronics, Box 73, Paramus NJ 07652

Sources for Hard-to-find Tubes:
Jaro Electronics, PO Box 414, Orlando FL 32802
U. N. Electronics, Inc., 1632 W. 31st Place, Hialeah FL 33012
United Page, 481 Getty Ave., Paterson NJ 07503

Used Commercial Equipment Dealers:
Electronic Distributors, Inc., 1960 Peck St., Muskegon MI 49441
Amateur Electronic Supply, Inc., 4828 W. Fon du Lac Ave., Milwaukee WI 53216
Buyers and Sellers (brokerage), PO Box 73, Boston MA 02215
Ham Trader (subscription), PO Box 311, Sycamore IL 60178

Chapter V

Antenna Systems

Simply stated, the purpose of any receiving antenna is to intercept a portion of an approaching wavefront, sense that part of the field as a potential difference across its conductive elements, and transmit that sensed voltage to the receiver.

Since an electromagnetic radio wave has both electric and magnetic components, an antenna may sense either or both of these characteristics; ultimately, however, it is an electric signal (rf voltage which reaches the receiver.

Although maximum signal strength is intercepted by high, large antennas, other factors must be taken into consideration in the design of an effective system; in many cases, neither large size nor height is an important as these other factors.

Because of the "law of reciprocity" (subject to much debate among communications engineers), a good transmitting antenna is a good receiving antenna; however, the reverse is not necessarily true. In actual practice, because of the wide dynamic range and weak-signal handling capability of modern receivers, receiving antennas are far less critical than transmitting antennas. We shall examine some of the considerations of antenna design one at a time, see Fig. 5-1.

Height. For proper low-angle signal response and predictable impedance matching and directivity, a horizontal dipole should be at least ¼ wavelength above actual ground at its lowest operating frequency; the higher the better. Feedline should lead away at a right angle for at least ¼ wavelength if possible.

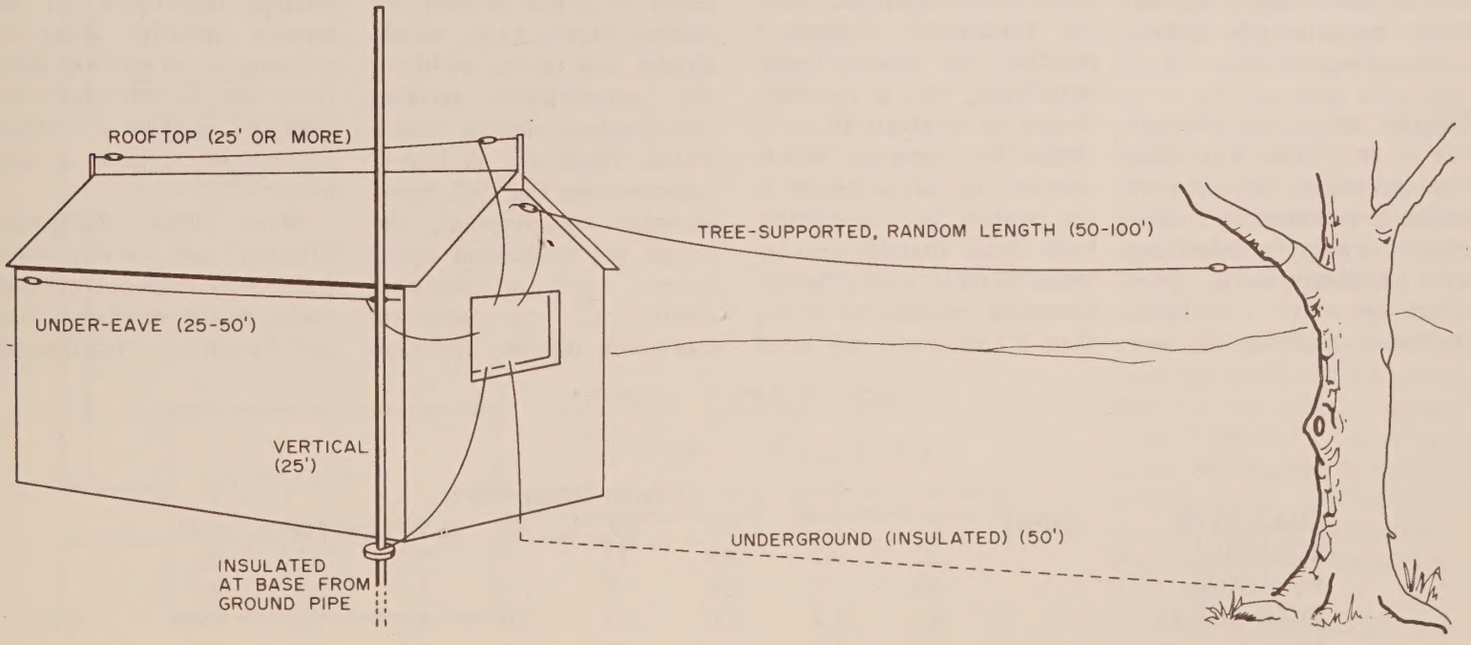


Fig. 5-1. A simple general purpose receiving antenna. Isolate all wire end supports with insulators. The wire may be insulated or uninsulated but it must be of a strong enough gauge to support its weight. The lead-in may be of the same wire as the antenna but care should be taken to guard against having the lead contact metal. For longer lead-in runs coaxial cable should be used.

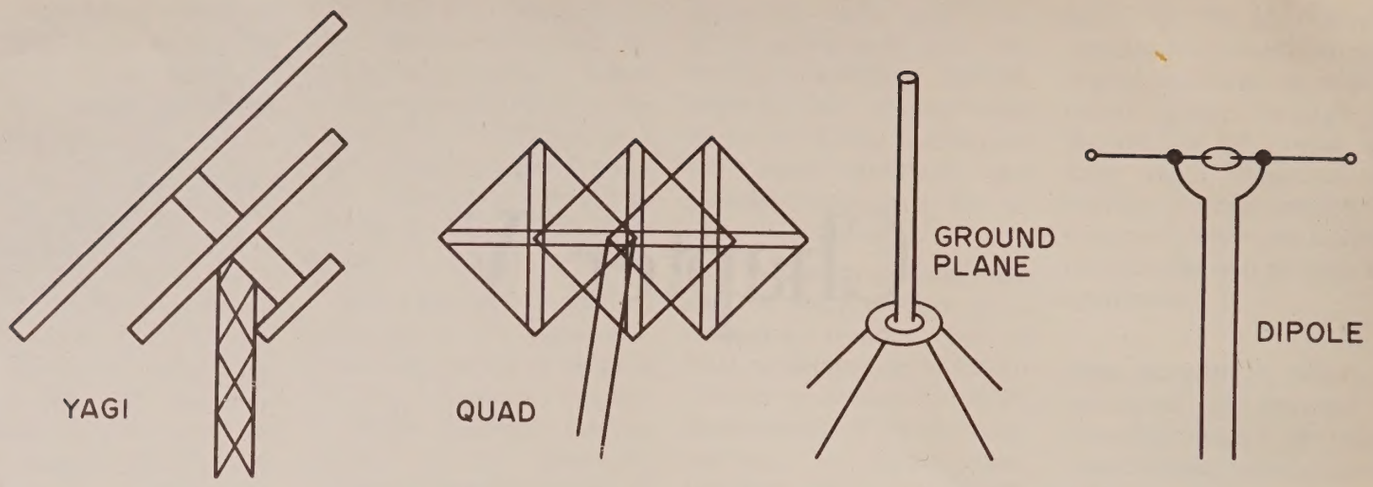


Fig. 5-2. High-Q (resonant) antennas have narrow bandwidths.

Vertical antennas may be ground-mounted if clear of obstructions and noise-radiating equipment, or else elevated on a rooftop or tower. At VLF or HF, the ground plane may be actual ground rods, or a ground return through power cords or plumbing. At VHF/UHF the ground plane takes the form of an actual counterpoise radial system.

Because of the surface-wave propagation phenomenon at low frequencies, LF and VLF antennas may be quite low; in fact horizontal wire antennas buried one or two feet under the ground are effective up to 3 or 4 MHz! At VHF/UHF the line-of-sight horizon is increased with antenna height, and the higher-the-better rule applies at these frequencies.

Capture area. The physical size of an antenna's conductive geometry governs its ability to intercept a quantity of radio energy for detection; with high-sensitivity, low-noise modern receivers, enormous antennas are not necessary for most applications. Pickup capability varies with the square of the wavelength. A 6 MHz half-wave antenna will sense 2500 times the signal strength of a 300 MHz half-wave antenna.

Impedance and resonance. Impedance is the complex resistive, capacitive, and inductive load represented by an antenna at its measured frequency; resonance is the signal-enhancing characteristic that certain antennas which are multiples of ¼ wavelength display at their design frequencies and their related harmonics.

Maximum signal transfer from an antenna to the receiver occurs when the antenna feed-point impedance matches the receiver input impedance; this is normally chosen to be about 50 or 70 Ohms (the free-space impedance of a half-wave dipole). If the system is mismatched, both signal strength and antenna directivity are affected. Generally, mismatches of less than 3:1 ratio are not at all critical, even for transmitting.

Mismatches may be corrected in a number of ways, most popularly by using a fixed impedance-matching transformer (as with a 4:1 balun), or an adjustable tuner or "matchbox", or by relocating the feed position between the antenna and transmission line.

Bandwidth. The frequency range over which the antenna displays a response within 3 dB of its design center is called its bandwidth; or, in the case of a parasitic beam, the bandwidth is defined as the range within which VSWR is kept below 1.75:1.

Most directional antennas have a relatively narrow bandwidth of a few percent, including beams, yagis, simple dipoles and quads; additionally ground-plane verticals also possess narrow bandwidth. These are all high-Q antennas, see Fig. 5-2. Some antennas are purposely designed for broadband applications such as discones, rhombics, log periodics, multi-wire dipoles, and cage or "fat" dipoles. Still others are effective on even or odd harmonically-related wavelengths, such as the Windom and center-fed dipole respectively. Practically any antenna may be brought to resonance by the use of a tuner.

Specific antenna recommendations will be made later in this chapter.

Gain. The improvement in signal strength delivered to the receiver by an antenna as compared with a reference half-wave dipole is called gain, and is expressed in decibels.

Beamwidth (aperture or directivity). Using wave-phasing techniques, an antenna's sensitive angle of response to an arriving wavefront may be narrowed considerably to favor directional characteristics. Gain is also improved.

Most simple horizontal dipoles are bi-directional (maximum response at right angles to the wire) near their self-resonant frequencies,

		Loss in dB per 100 ft.							
COAX TYPE	f(MHz)	3	7	14	20	30	50	150	450
RG8/AU/U		.32	.47	.68	.77	1.0	1.5	2.6	4.5
RG11/AU/U		.40	.57	.92	1.0	1.2	1.6	2.7	4.7
RG58/AU/CU		.93	1.4	2.0	2.3	3.0	4.2	7.8	13.5
RG58/U		.73	1.0	1.4	1.9	2.4	3.9	5.9	10.2
RG59/AU/U		.68	.96	1.2	1.5	1.9	2.5	4.2	7.3

Fig. 5-3. Signal attenuation of common coaxial cable at various frequencies.

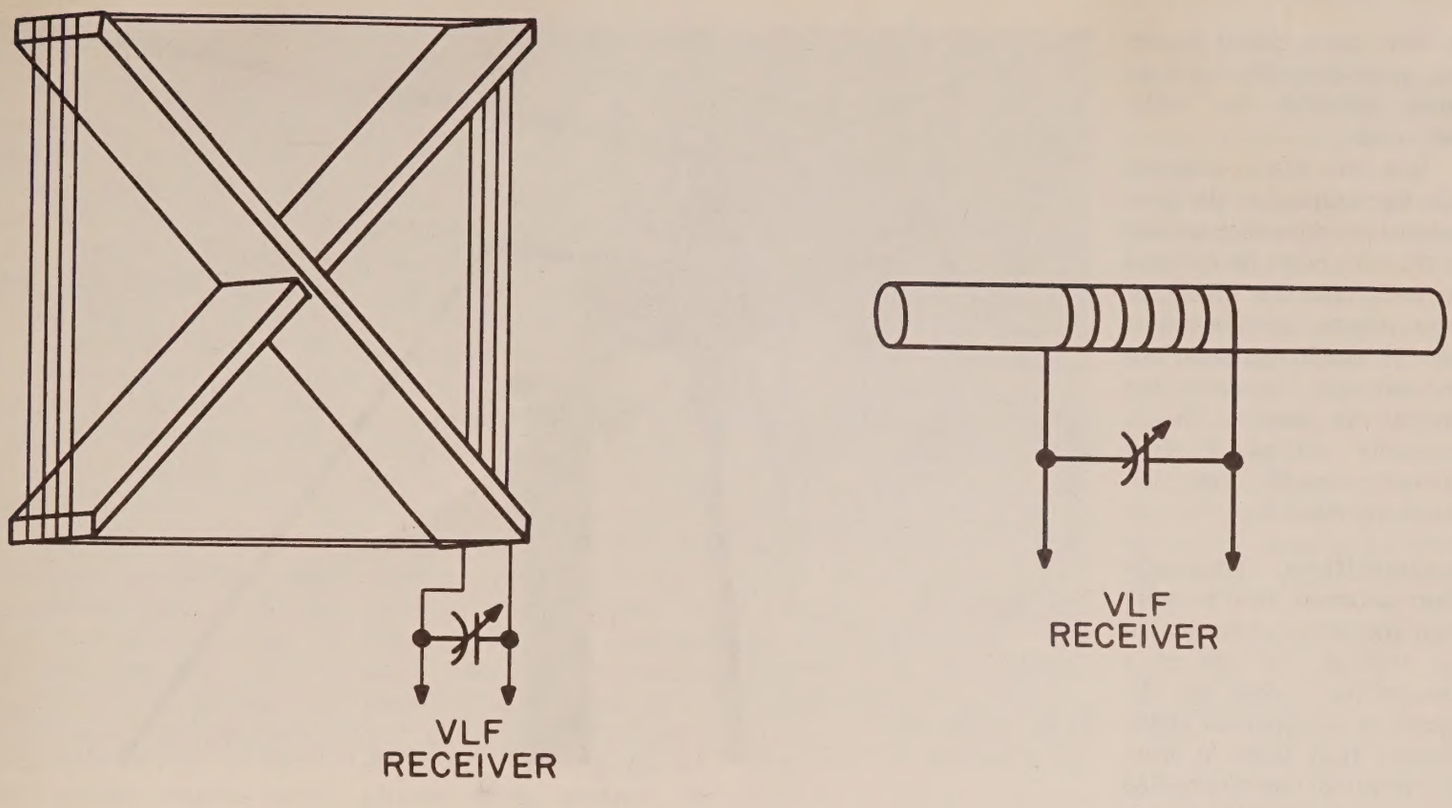


Fig. 5-4. Two common indoor VLF loop antennas are the obsolete open frame and the ferrite rod.

while simple vertical elements are omnidirectional.

The addition of parasitic reflector and director elements restricts the beamwidth in varying amounts, depending upon their sizes and relative positions in reference to the main element.

Transmission lines. Low-capacity coaxial cable is recommended for receiving systems (Fig. 5-3); although open-wire feeders are the least lossy, the electrical-noise immunity of coax makes it the better choice in populated areas. Losses only become a concern above 30 MHz when cable runs are in excess of 100 feet; here, low-loss foam-dielectric coaxial cable is recommended. An antenna preamplifier is helpful at VHF/UHF if transmission-line losses pose a problem. Below 30 MHz, RG59/AU is perfectly satisfactory; at VLF use the shortest run (a few feet) of coaxial cable possible. Signal losses will be high due to the short, capacitive antenna at low frequencies.

At VHF/UHF, low-loss coaxial cables such as foam-dielectric foil-shield TV transmission line or RGII/AU works well. Open-wire twin lead and TV ribbon with their inherent noise susceptibility, feed-through losses, and straight-run requirements, are no longer necessary although they do provide the lowest loss.

Mechanical considerations. Metal junctions encourage electrolytic corrosion; soldering is recommended. If soldering is not possible, conductive anti-corrosion paste should be applied to the junction to prevent oxidation. Silicone rubber or epoxy potting may be used to weather-seal connections. Acrylic sprays or plastic electrical tape provide temporary protection only.

Antennas should be free and clear of close-horizon obstructions including dwellings, trees, and metal fencing; height is usually the solution

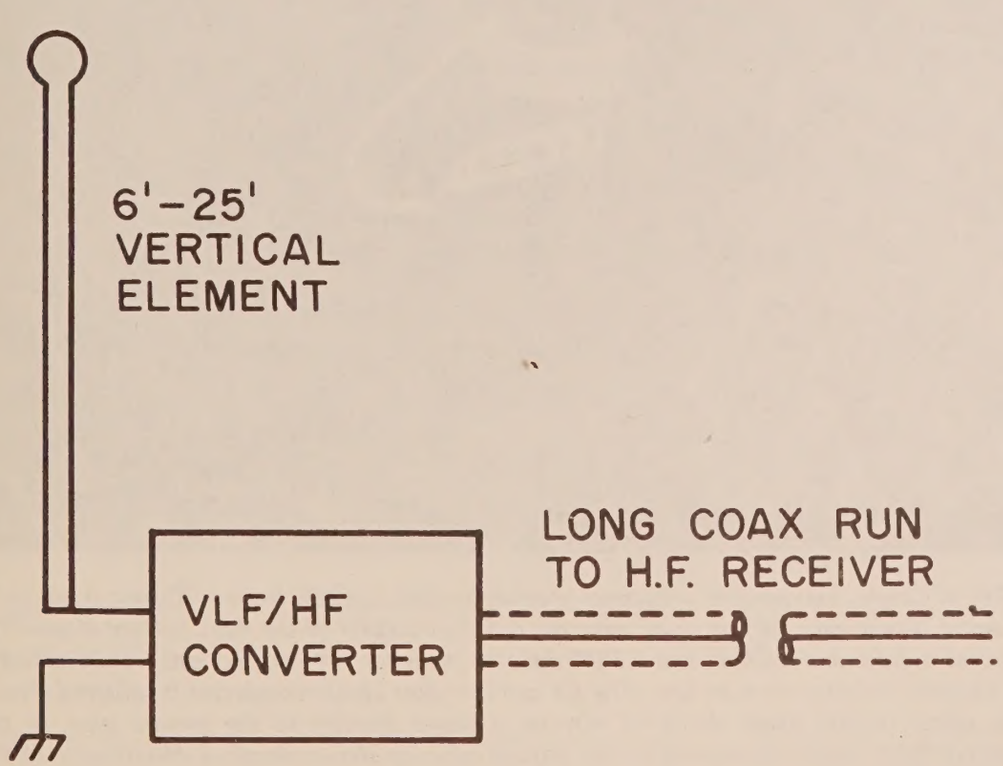


Fig. 5-5 Effective VLF/HF up-converter scheme to overcome capacitance-less effect of long coaxial cable run.

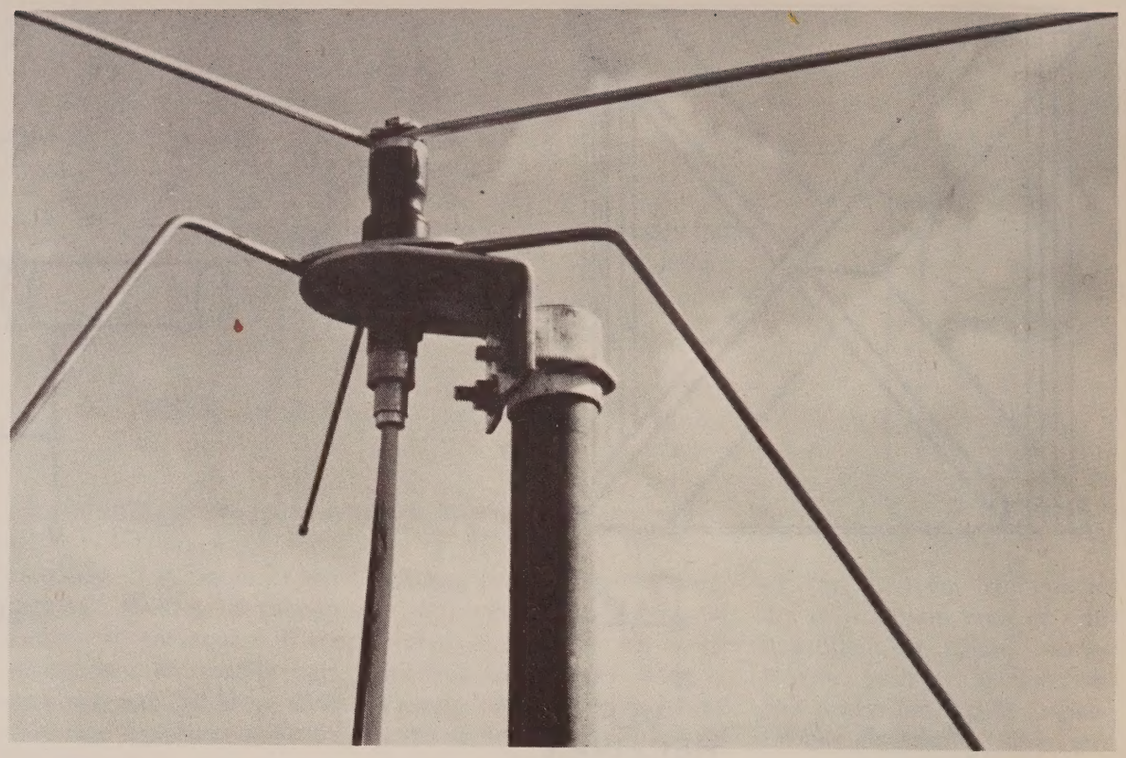
in these cases. Metal towers and masts are lightning rods; they should be well-grounded.

Two or more antennas may be mounted on the same support provided they are not in the same plane (one should be well above the other), or they may be separated by at least ½ wavelength so as not to seriously interact and distort the pattern. This is especially critical if their element lengths are harmonically related.

Preamplifiers. Physically-short antennas may be more than adequately compensated for through the use of a preamplifier. Some are designed to be mounted at the antenna feed- point in order to overcome transmission-line losses and noise; DC power is fed through the transmission line. Others may be connected at the receiver antenna input, amplifying signals brought in by the transmission line. Of the two types, the antenna-mounted preamplifier is recommended, especially at VHF/UHF in order to overcome transmission-line noise and signal attenuation.

Broadband preamplifiers uniformly (or nearly so) amplify all signals in their passband, usually many megahertz wide. Several multiband antenna preamplifiers are available which simultaneously amplify signals in the 30-50, 150-174, and 450-512 MHz public service bands while rejecting out-of-band signals. Others are available for virtually any frequency range of interest, including those with narrower passbands.

Antenna switches. Multi-position antenna switches for coaxial transmission-line selection are useable through at least 30 MHz. VHF/UHF switching is not recommended because of VSWR losses which may become significant in low-cost switches at these frequencies; VHF/UHF coaxial switches and relays are available if



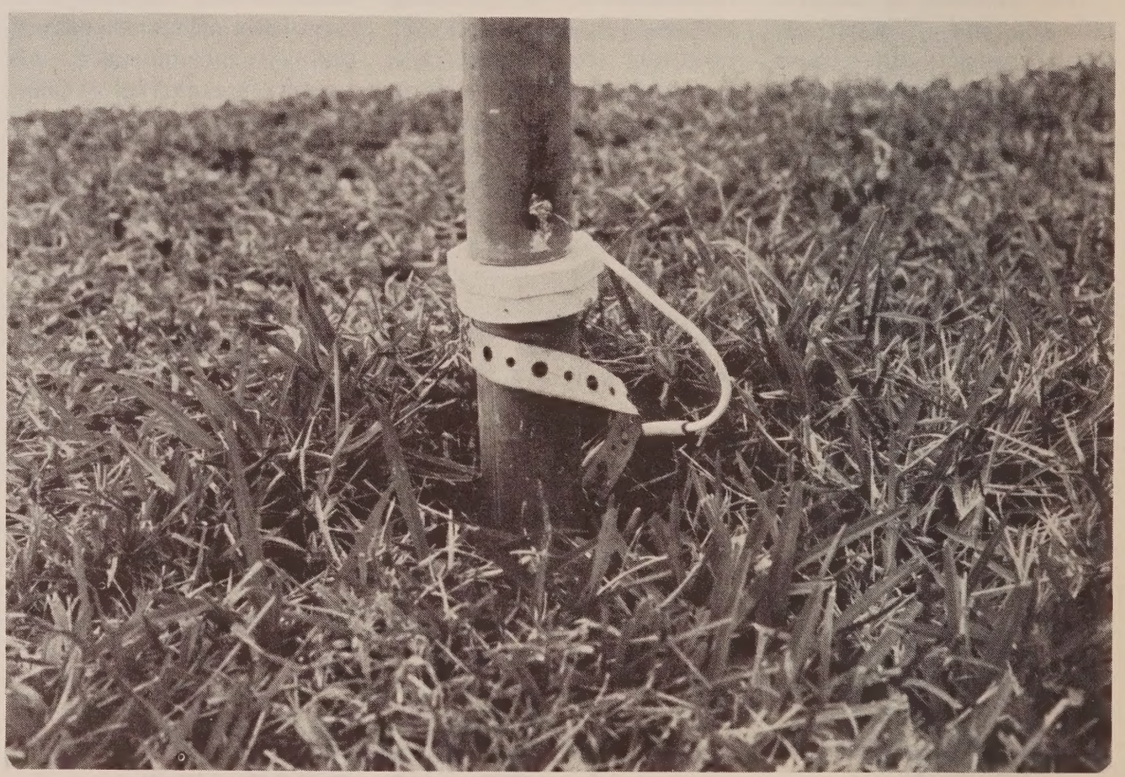


Fig. 5-6. A simple, inexpensive wideband antenna system is made from a 30-foot push-up TV mast and a Newtronics DCX discone antenna. A 5-foot section of the mast bottom is sawed off to become a grounded support and a PVC adaptor insulates the two sections from each other, while securely holding them in line. The HF coaxial cable center conductor is soldered directly to the upper section while the braid may be soldered directly to the ground pipe, or to a galvanized strap which is soldered to the ground pipe (as shown here). A Newtronics Hustler DCX discone antenna is securely mounted at the top of the mast, insulated by a sleeve of PVC (if the PVC is too tight to slip over the pipe, it may be cut down one side and expanded). The VHF/UHF coax is then looped up and passed down through the opening at the top of the pipe, and out through a slot out at the bottom of the mast (not shown).

their use is mandatory.

Preselectors. A good preselector is actually a high-Q tuneable RF stage connected between the antenna feedline and the receiver input, it may help overcome several reception weaknesses including images, low sensitivity, front-end overload and intermodulation, and an inadequate antenna. A well-designed monitoring station does not require a preselector.

Lightning protection. Any outside antenna is a lightning rod; proper grounding is essential. Even nearby strikes can inductively damage receiver input circuitry. During prolonged periods of equipment disuse, antenna cables should be disconnected entirely. The receiver chassis itself should be well-grounded.

Through-line lightning arrestors ("Blitz-bugs") should be installed on all inside coaxial transmission line connectors. Metal towers and masts are recommended for their inherent conductive protection in case of an actual direct strike. Protective diodes may be installed at all receiver antenna inputs, as well as transient suppressors and fast fuses or circuit breakers on power lines. If feasible, a grounded antenna-shorting switch should be installed at the receiving position for each downlead; a multi-position antenna switch with one grounded position is effective. A heavy-gauge RF choke from antenna to ground also provides protection from static electricity, but inductance must be large enough to avoid interaction with the antenna's response at low frequencies.

VLF ANTENNAS.

Conventional antenna practices have historically been used at very low frequencies; most early long-wave radio stations used high and large wire antenna systems. Receive-only installations have used open-frame loops, and more recently, ferrite-core "loopstick" antennas (Fig. 5-4).

Because of the long wavelengths involved, indoor loop antennas are often satisfactory, as they encounter a minimum of phasing and reflectivity problems. Electrical interference may be severe near electrically-operated equipment; it may be reduced by rotating the loop for minimum noise pickup. Loops are also useful for radio direction finding.

Often, a vertical ground-mounted or roof-mounted whip is highly satisfactory, especially when impedance-matched by an antenna tuner and feeding a sensitive receiver; listeners report distant reception with a six-foot whip antenna.

Vertical polarization is also recommended for lower power line noise interference and better signal-capturing ability.

Buried antennas less than one meter beneath the surface of the ground may be useable to frequencies as high as 3 or 4 MHz; approximately 50% reduction of length from free-space formulas is sug-

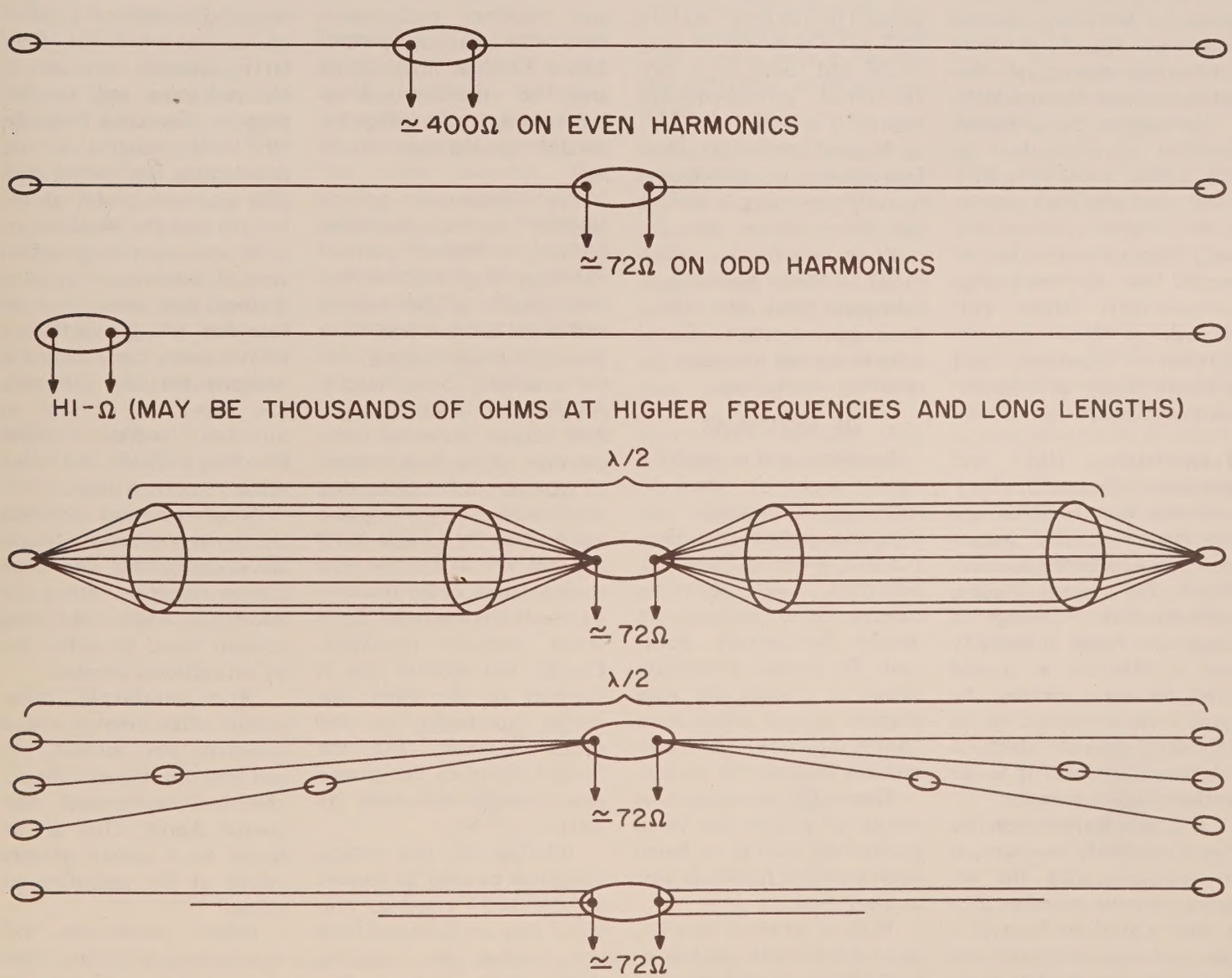


Fig. 5-7. Several approaches to wide frequency coverage at HF.

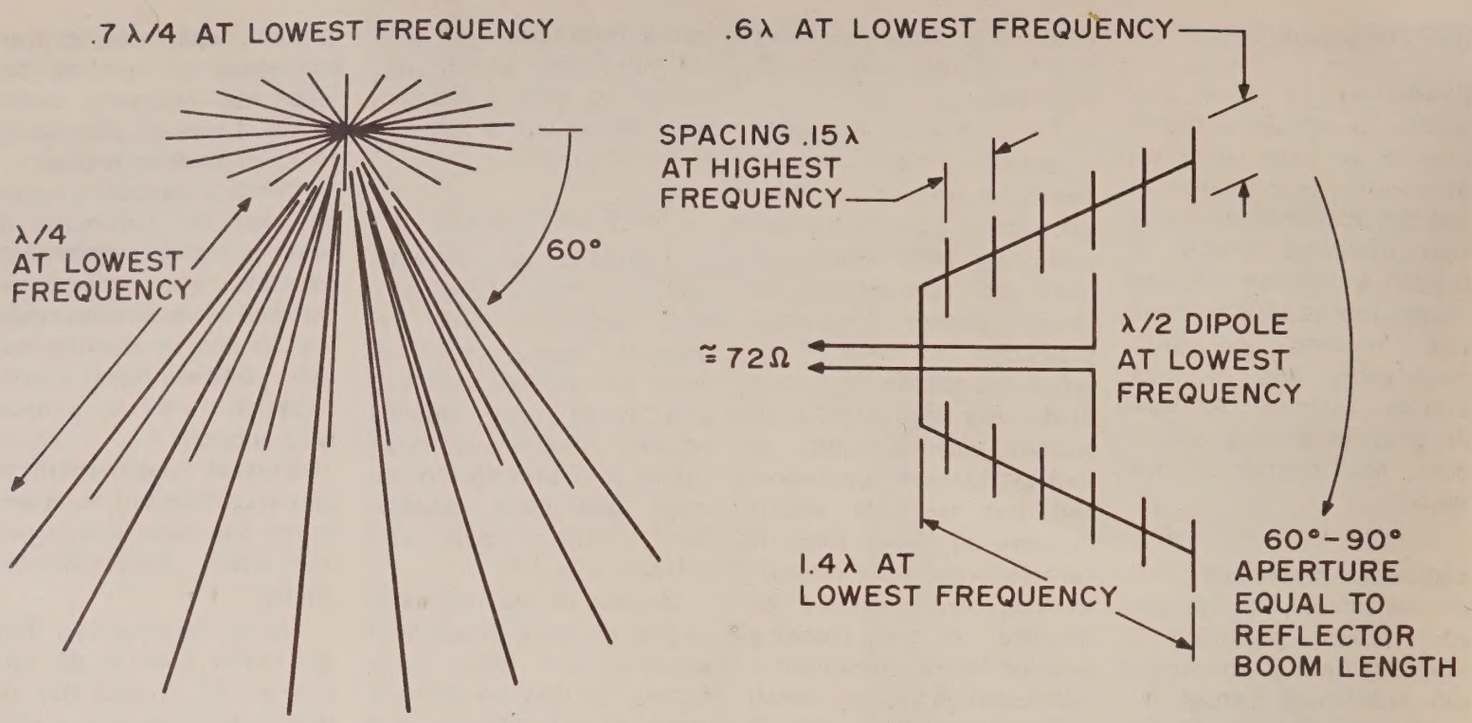


Fig. 5-8. The discone (omnidirectional, vertically polarized) and the trough reflector (directional, selectable polarization), two popular VHF/UHF antennas.

gested. Generally, buried antennas suffer sharply from attenuated pickup at frequencies above about 6 MHz.

Voltage-probe antennas combine physically-short (a few inches) elements with a solid- state amplifier, and are as effective for receiving as a whip antenna several feet in length. Their frequency range is typically from VLF through 30 MHz. They are relatively expensive, and available from government-contract vendors.

Transmission lines and grounds. Generally, VLF antennas and feedlines are electrically very short; impedance matching the feedline to the antenna is not a consideration. Although a single-wire feeder is probably just as effective as coaxial cable for signal transfer, the coax is recommended for its shielding against electrical interference, which is severe at these low frequencies.

If a long transmission-line run is absolutely necessary, as in remote-locating the antenna for noise isolation, then a tuner should be located at the antenna feedpoint to match the system. Better yet, an up-converter may be substituted for the tuner, and the VLF range is fed to the coax as HF and tuned by a conventional general-coverage receiver (Fig. 5-5).

A good ground at these frequencies is mandatory. Generally speaking, a six-foot rod driven down into the earth is satisfactory; alternately, a metal plumbing (a cold-water pipe) may offer a good ground return. Radial systems are not necessary for receiving installations.

HF ANTENNAS

Polarization of transmitted signals varies in the HF spectrum; land-mobile services and tactical operations are almost always vertically polarized, while point-to-point fixed services are usually horizontally polarized. To further complicate things, an arriving sky wave displays mixed polarization characteristics, although possibly favoring the vertical.

Generally speaking, the choice of polarization for a monitoring station is based upon practical factors as well as theoretical.

With a sensitive receiver, and a tuner at MF and below, a 25-foot ground-mounted vertical out in the open will give excellent performance from VLF to about 50 MHz. Above 30 MHz, however, its angle of radiation and reception becomes too high for reliable ground-wave coverage.

An inexpensive vertical antenna may be constructed utilizing a 30-foot push-up TV mast (Fig. 5-6). A five-foot length of the bottom end is cut off and used for a ground pipe and support for the remaining 25-foot length. An insulator such as a flanged PVC adaptor is inserted at the juncture of the two sections to separate and stabilize that point; upper support is provided either by a brace to an adjacent wall in the case of a close antenna, or by insulated guy lines (nylon rope) for a more remote location. Coaxial transmission line is soldered to the pipes; the center conductor to the upper element, and the braided shield to the ground pipe beneath the base insulator.

Additionally, this vertical mast may be used to support a VHF/UHF antenna, provided they are insulated from one another. An insulating sleeve made from a few inches of PVC pipe and covering the upper few inches of mast on which the VHF/UHF antenna bracket is clamped serves well for this purpose. The coax from the VHF/UHF antenna is run down inside the vertical mast pipe and out a slot at the bottom near the insulator.

A physically-grounded vertical antenna, such as a 30-foot pipe sunk three or four feet into the earth as a counterpoise, can function if properly fed; the extremely low impedance of such an antenna feedpoint makes matching difficult, and such a system is seldom used.

Simple vertical antennas are omni-directional; this is an advantage for maximum-station reception, but a disadvantage when interfering stations could be nulled out by a directional antenna.

More elaborate installations often employ several antennas: one vertical, one east-west horizontal dipole, and one north-south horizontal dipole. They are selected by a coaxial antenna switch at the operating position.

Indoor, under-eave, wall wrap-around, and other forms of compromise HF antennas should not be considered if

any kind of outside antenna is possible; such inferior antennas are generally noise-prone, erratically directional, and lossy due to nearby wiring, plumbing, and air ducting. Only at VLF are indoor antennas recommended.

Although some monitoring applications may require elaborate antenna arrays and complex phasing networks to detect extremely distant weak signals, simpler antennas at least 25 feet in length will suffice for the majority of receiving installations.

More elaborate HF antenna systems provide higher gain and reduced beamwidth; they include Sterba curtains, phased dipoles or vertical elements, log-periodic beams, wire discones, and terminated rhombics.

Since any antenna, long or short, may be tuned to resonance by cancelling inductive and capacitive reactances, self-resonant lengths are not mandatory. For general-coverage applications, a tuner is recommended with any resonant antenna.

To maintain a symmetrical pattern, balun transformers are recommended at the feedpoint between a balanced antenna and coaxial (unbalanced) transmission line.

Windom. (Fig. 5-7A) this half-wave dipole is fed 14% off-center, a point which maintains a relatively constant impedance of several hundred Ohms on even-harmonic frequencies. A 160-foot horizontal Windom is resonant at 3 MHz, but matches closely at 6, 12, 18, 24, and 30 MHz. Its pattern is the same as the doublet to be described below. If matched at the feedpoint by a 4:1 balun transformer, impedance is reduced to a level where the antenna may be fed by standard RG59A/U coaxial cable and present a reasonable match at the receiver. It may also be fed by a single wire or TV twin-lead.

Even without a tuner or matching transformer, the Windom antenna is one of the best choices for a general-coverage shortwave receiving antenna. Its self-resonant half-wave length may be shortened if necessary with only a small loss in performance at lower frequencies. An 80-foot Windom is still an excellent choice for an all-wave HF antenna.

Doublet. The center-fed dipole or "flat-top" is the most common half-wave horizontal wire antenna; it is the standard of comparison for other antennas. Displaying a free-space resonant impedance of about 70 Ohms, it may also be used on odd harmonics with close impedance match; a 160-foot center-fed doublet will provide good performance at 3, 9, 15, 21, and 27 MHz.

Its characteristic impedance increases with each successive harmonic interval; its bi-directional pattern also changes, creating multiple lobes nearing the axis of the wire.

A 1:1 balun transformer is recommended when feeding a balanced antenna like a doublet with coaxial transmission line.

Hertz. (Fig. 5-7C). An end-fed wire 25 or more feet in length, even if casually looped over a high tree branch, makes a good antenna when properly tuned. When not cut to resonance, it is called a "random-length" antenna; otherwise, the end-fed Hertz is normally considered some multiple of a half-wavelength.

Proper matching with any length at any frequency may be accomplished by a tuner.

Broadband antennas. Much of the narrow-band characteristic of wire dipoles is the result of thin conductor size compared to length; by increasing conductor diameter, bandwidth is broadened considerably, often as much as a 3:1 frequency range. Such "fat" dipoles include the cage and multi-wire antennas (Fig. 5-7D).

Another technique at broadbanding is accomplished by the use of non-resonant antennas like the terminated longwire and the rhombic; the rhombic combines broad bandwidth with exceptionally-high directive gain, increasing with frequency on a given antenna.

Multiband dipoles (Fig. 5-7E&F). A cluster of center-fed dipoles of various lengths tied together at their common feedpoints, and fed by one feedline, makes an effective multiband dipole. Dipoles with series inductive-capacitive wavetraps are also available from several manufacturers as an alternative approach at maintaining a relatively constant impedance over a wide range of frequencies.

Again, the use of a tuner will bring any simple length of wire to resonance where needed, making such complex impedance-matching techniques unnecessary.

VERTICAL ANTENNAS

The simplest effective vertical antenna for use throughout the entire HF spectrum and below, is the 25-foot vertical described earlier in this chapter; when tuned by a matching network at the operating position, it is capable of performance equal to any single-element vertical antenna configuration of that height, including a trap vertical. Even without the tuner, it is satisfactory for most receiving applications at shortwave frequencies. Be sure to use a good ground.

Trap verticals. Usually designed for amateur radio bands and expensive, trap verticals are no better for general-coverage use than a tuned vertical. They are good antennas, however, and if already in use with an amateur transmitting installation, their use for general-coverage reception is certainly adequate.

The construction of an effective continuously-loaded, helically-wound vertical for broadband coverage was described by H L Booth (ZE6JP) in Ham Radio Mag-

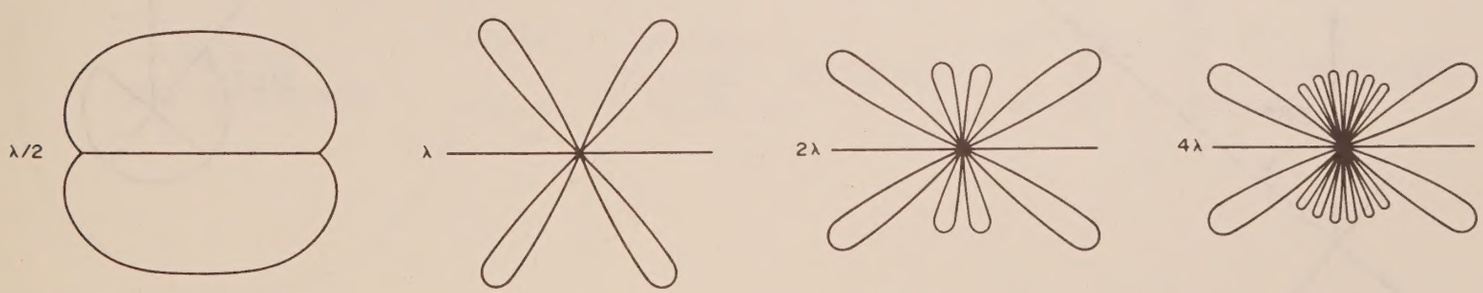


Fig. 5-9. An illustration of how major lobes change as a dipole becomes electrically longer. Notice how major directivity becomes more collinear with the dipole axis with increasing wavelength. Thus an East-West axis dipole at lower HF favors North-South ground wave for stateside coverage, but favors East-West skip for higher frequency DX.

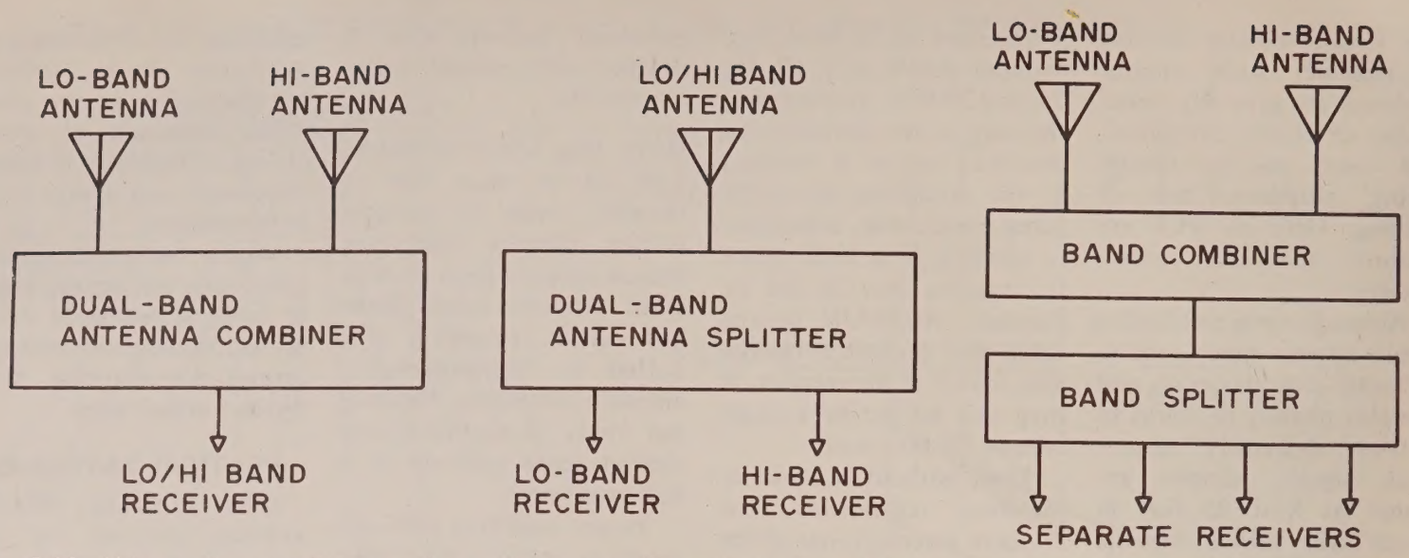


Fig. 5-10. Using antenna splitters and combiners, a wide variety of combinations are possible to satisfy every receiving requirement.

azine, December 1972.

VHF/UHF ANTENNAS

In virtually every case, the limiting factor in VHF/UHF communication is receiver noise; electrical interference is not so severe as at lower frequencies.

Because of the shorter wavelengths exhibited by VHF and UHF signals, resonant and directional antennas tend to be physically small; this has the advantage of providing for simple, lightweight construction of high-gain directional antennas. A disadvantage lies in the smaller capture area which requires receivers of considerably higher sensitivities than those used at longer wavelengths.

VHF and UHF communications are almost universally vertically polarized. Antennas vary considerably; ground planes, yagis, log periodics, corner reflectors, discones, longwires, rhombics, and parabolic dishes are the most common (Fig. 5-8).

Ground planes. Because of the perpendicular geometry of the ground plane antenna, feed-point impedance is close to 50 Ohms (or less); drooping radials are recommended for closer impedance matching. In actual practice, 50 or 70 Ohm coax is perfectly satisfactory. Ground planes are cut to resonance with quarter-wavelength radial elements, and multiples of ¼ wavelength for the vertical element to provide some gain. Resonance is several megahertz wide at these frequencies because of element diameter.

Ground planes are by far the most popular vertical

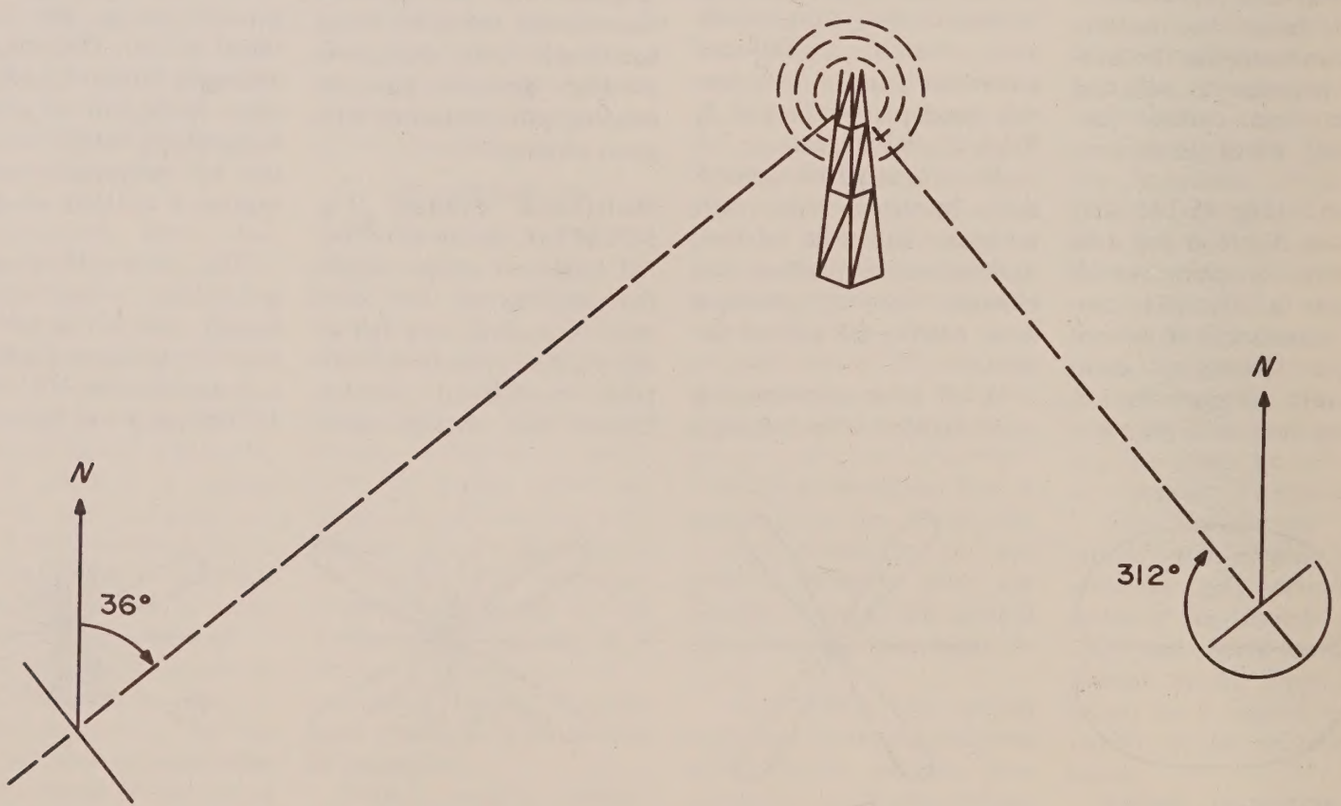


Fig. 5-11. Two ambiguous (bidirectional) bearings can resolve the location of a target transmitter.

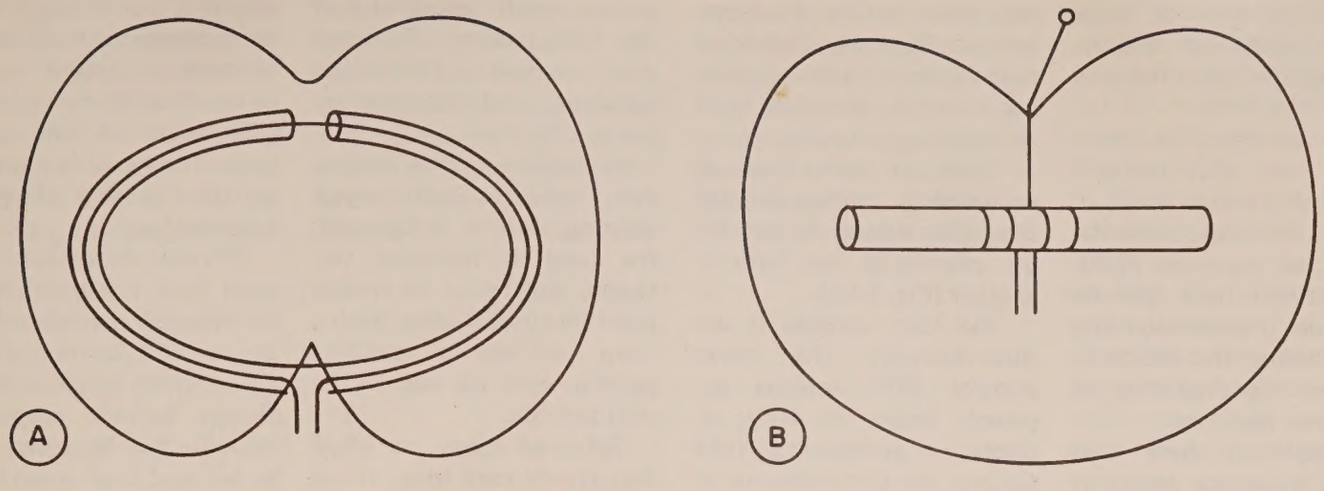


Fig. 5-12. The bidirectional pattern of a simple loop (Faraday-shielded) (A), and the unidirectional cardioid pattern of a compact sense antenna/loop combination.

VHF/UHF antenna configuration used in VHF communications.

Yagis. This VHF beam antenna provides high gain and light weight; because of its phase relationship, its bandwidth is only a few MHz wide at the most. It may be mounted for either vertical or horizontal polarization.

Log periodics. This antenna is an array of incremental-length dipoles, cross-phased and commonly connected to a phasing bar. It combines high gain with wide (usually 3:1) bandwidth. As with the Yagi, it may be vertically or horizontally polarized.

Many TV antennas make use of this technique; they may be modified for communications monitoring by pruning element lengths and matching the feed point with a 4:1 VHF/UHF balun for use with coaxial transmission lines, or fed with 300 Ohm TV twin-lead.

Corner reflectors. These are also popular TV antennas because of their wide bandwidth; using a broadband bow-tie as the tuned element, the corner reflector may provide excellent gain as well as a 2:1 or greater bandwidth. Either vertical or horizontal polarization may be selected.

Discones. Very popular for wideband military VHF/UHF communications, the discone possesses one of the widest bandwidths available. It is in excess of 10:1!

Discones are vertically-polarized and omnidirectional, and respond to all frequencies within their bandwidth; thus, interfering signals from nearby FM or TV broadcast stations may present a problem, but they are easily filtered by properly constructed wavetraps.

Longwires and rhombics. A wire antenna which is long in terms of wavelength possesses major lobes of sensitivity approaching the direction of the wire's axis (Fig. 5-9). If a location of listening interest lies in one particular geographical direction, a wire antenna several wavelengths long (like a Beverage antenna) may prove useful; its polarization is horizontal.

Unidirectional characteristics are enhanced by phasing two longwires into a "V", or four longwires into a rhombic. Very high gain is possible with such a configuration, while still retaining wide bandwidth.

Parabolic dishes. Because of the physical size, weight, and expense of parabolic reflectors, their application is primarily confined to UHF and above. Higher gain is possible, but the Yagi or log-periodic is recommended for physical practicality.

Splitter/combiners. Antenna flexibility may be greatly extended through the use of splitter/combiners in various combinations. Actually a splitter and a combiner are the same device . . . hooked up backwards! Electrically speaking, they are frequency-sensitive impedance-matching transformers; they may be broadband, narrowband, or multiband.

As a splitter, the device serves to permit two or more

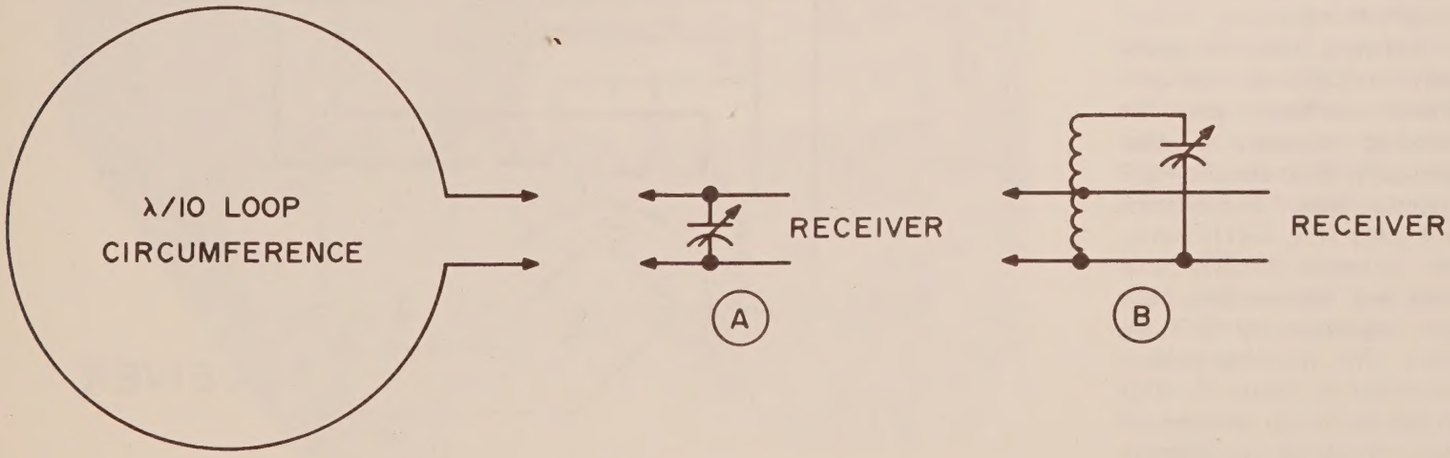


Fig. 5-13. Resonating the loop with a capacitor (A), or better yet with a tuned circuit (B) will vastly improve sensitivity and gain.

receivers, or two or more antenna inputs on one receiver, to operate from one antenna (Fig. 5-10).

As a combiner, the device permits one wide-spectrum receiver to utilize two or more antennas simultaneously; or, an entire multiband antenna field may be fed by one transmission line by combining the antennas, and then signal-splitting at the receiver positions.

Bandsplitters have two separate frequency ranges in their split sides to prevent interaction among commonly-fed equipments. General-purpose devices are available from most radio parts jobber, especially mail-order houses.

Splitter/combiners may be cascaded for even greater system flexibility. Unused ports should be terminated with a noninductive resistance, usually a 70 Ohm, ½ Watt carbon composition resistor, to maintain system balance.

RADIO DIRECTION FINDING ANTENNAS

Below 30 MHz. The principles of antenna directivity are not only useful for rejecting interfering signals, they also provide a convenient means of signal locating. The azimuth, or bearing, of an approaching wavefront may be determined by orienting the antenna for either a peak in signal strength, or a null; generally, the null is sharper, thus providing better resolution of the signal's direction.

Antennas may be physically rotated, or multiple-phased elements may be switched manually or electronically. Most simpler RDF systems have bidirectional ambiguity (Fig. 5-11); that is, the antenna displays two nulls and two maxima, each pair separated by 180 degrees. The resulting pattern resembles a figure 8. This ambiguity is no problem if two locations co-ordinate their bearings, permitting the co-ordinates to be drawn on a map; they will cross at only one point within the hemisphere. But one individual plot will be on a line extending in either direction from the receiving antenna.

There are many ways of overcoming ambiguities of direction; almost all of them use phasing in one form or another (Fig. 5-12).

The loop antenna is unquestionably the most popular RDF antenna approach below 30 MHz; to display a symmetrical field pattern, the circumference of the loop should be no greater than 1/10 wavelength at the highest frequency at which it is to be used. This prohibits the formation of standing waves which would distort the field pattern. The loop does not have to be circular; rectangles and triangles are just as effective.

A simple loop may be used for unidirectional signal locating if it is unbalanced; the loop is mounted vertically, and fed at its broken point by coaxial cable. Such a loop exhibits a cardioid pattern, with the null on the shielded side.

Balanced loops are often Faraday-shielded to eliminate capacitive pickup of stray electrical signals.

Another approach to derive unidirectional performance from a balanced loop is by combining it with a sense antenna, a small vertical element mounted a few inches away from, and in the same plane as, the vertical loop. The result is a cardioid pattern like that of the unbalanced loop.

Physical dimensions of the open loop construction may be reduced considerably by the use of a ferrite rod form; a 6 or 8 inch length of ferrite, chosen for the proper mu value for the frequency range to be used, and wound with small-diameter wire, provides good performance.

Because of the small physical size and low characteristic impedance of simple

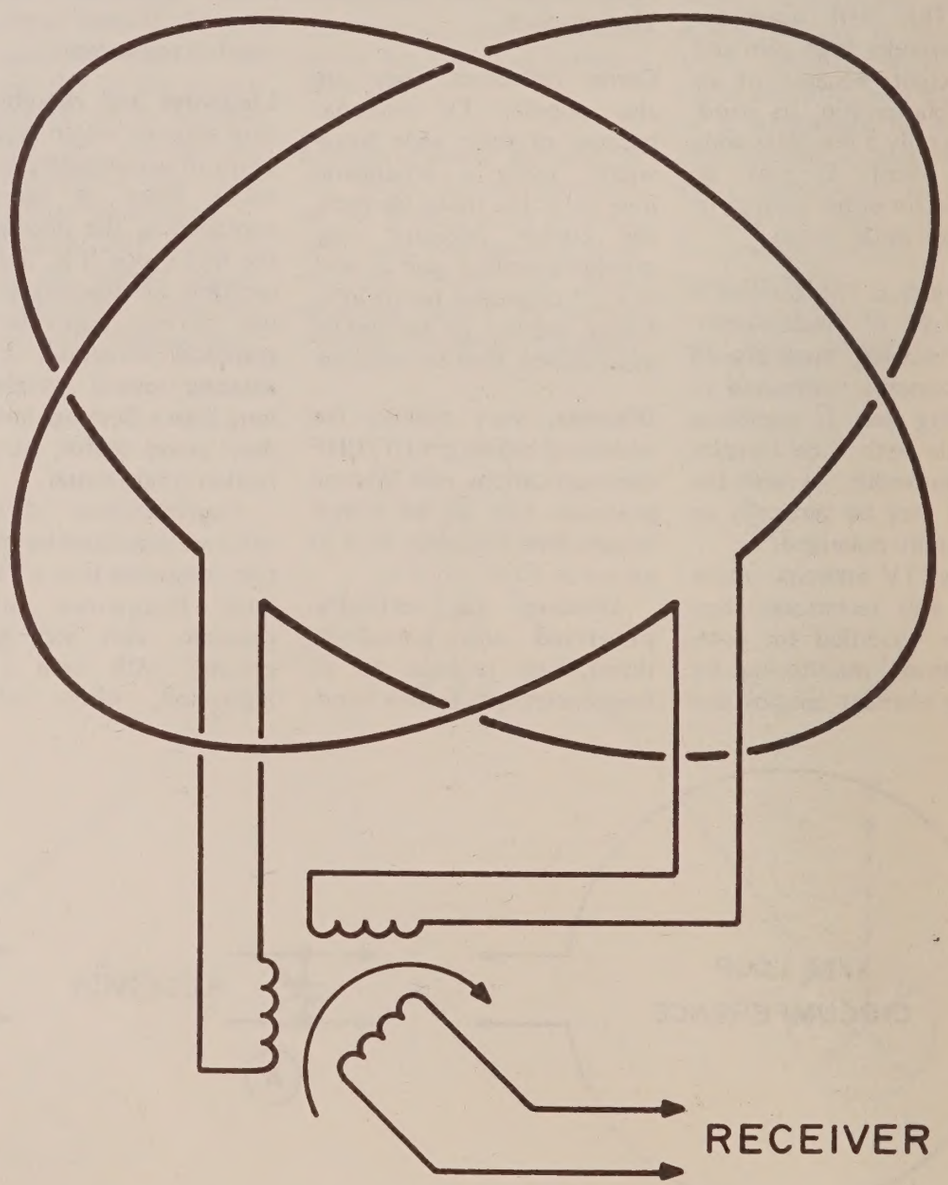


Fig. 5-14. The Bellini-Tossi fixed loop goniometer selects bidirectional azimuth by rotating the coupling coil for null between two perpendicular loops.

RDF loops, tuning or matching is recommended for optimum signal transfer to the receiver. This may be accomplished by resonating the loop by a parallel tuning capacitor at the feed-point, or by feeding the loop-antenna transmission line into a simple tuner ahead of the receiver (Fig. 5-13).

The Bellini-Tossi fixed-loop goniometer is an example of an electronically-steerable loop antenna system (Fig. 5-14). Two balanced vertical loops are mounted coaxially at 90 degrees to one another; their transmission lines terminate at the operating position in two coupling link coils, also mounted at right angles to each other. Directional resolution is provided by a pickup link which rotates between the two coupler coils; the shaft of the link is connected to an indicator calibrated in azimuth degrees.

Fixed phased arrays are narrow-bandwidth systems which rely upon their relative spacing and position at a given wavelength to provide directivity; they are reasonably sharp in directivity, but their directivity must be incrementally-tuned by switching combinations of antenna elements. Such systems are generally constructed to favor specific directions for point-to-point communications.

Two fixed vertical elements may be used over a limited frequency range as an RDF if their transmission lines are brought into a common phase control/amplitude balancer. A common input signal is adjusted for identical amplitude output from both antennas; the phasing control compares the arrival times of the radio signal at each antenna, resolving the difference in wave-phase as a difference in azimuth.

Common RDF systems are accurate to only a few degrees at best, and optimum conditions are seldom present. Degraded performance is contributed by multipath, the simultaneous arrival of a radio signal from more than one direction (Fig. 5-15). The resulting complex phasing of the wavefront makes accurate resolution impossible. Contributing factors to multipath include atmospheric refractions and reflections, ground-wave and sky-wave components, and reflective obstructions.

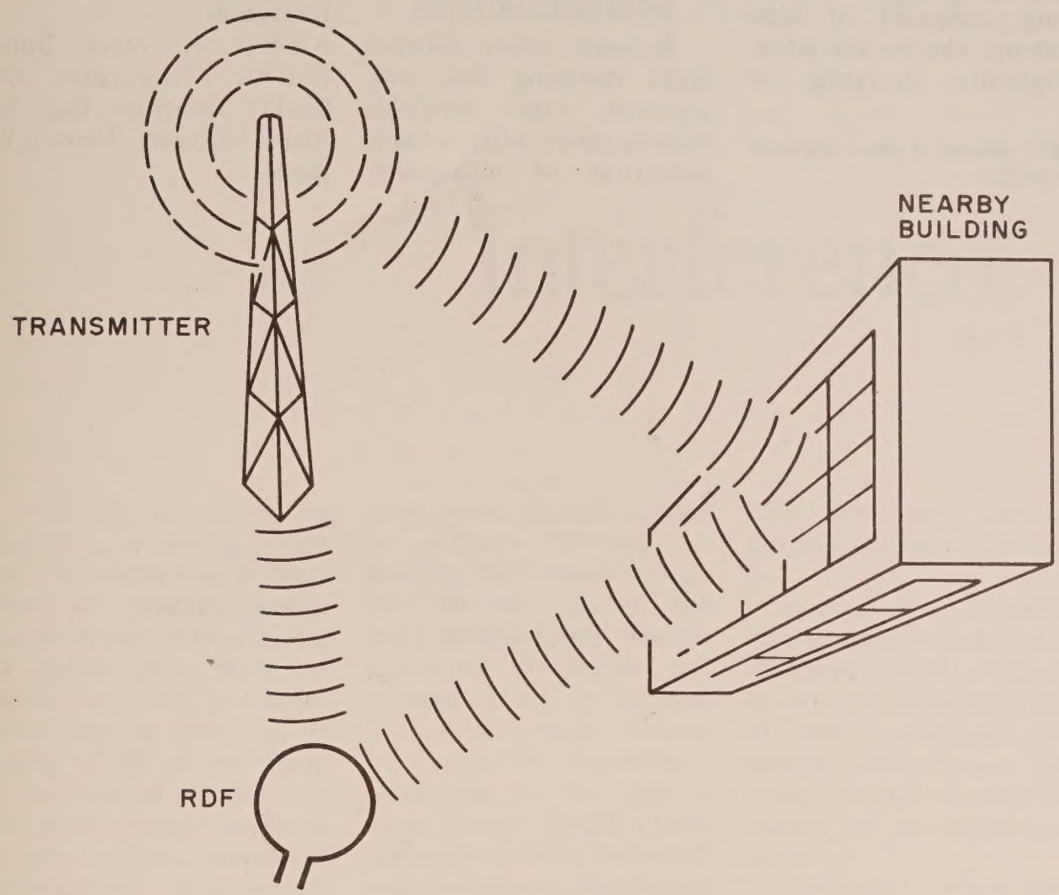


Fig. 5-15. Multipath caused by reflected waves confuse RFD senses.

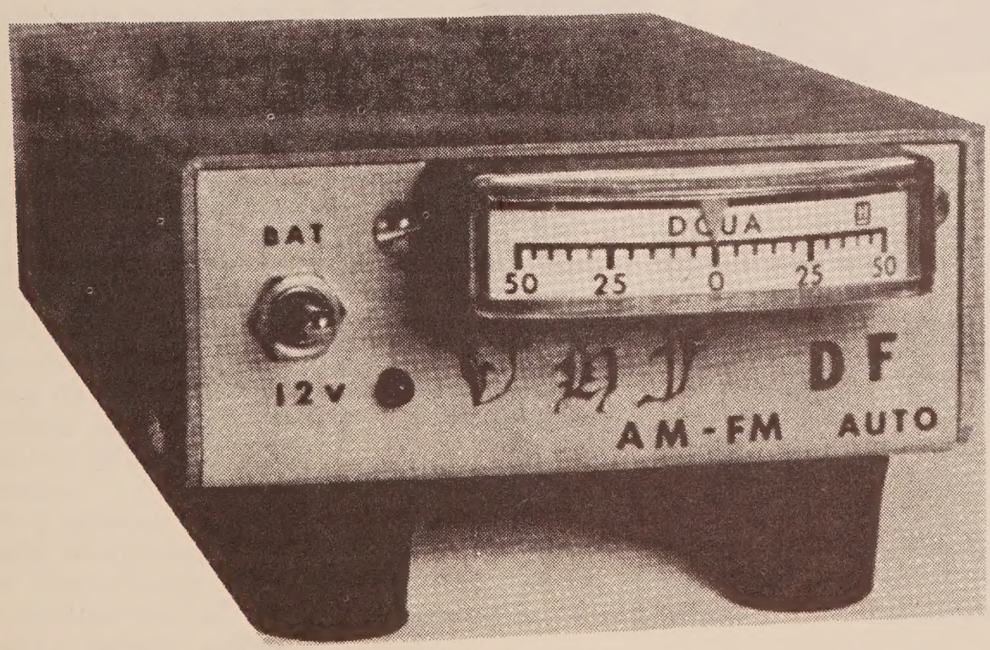


Fig. 5-16. Radio Direction Finding unit produced by the Happy Flyers.

VHF/UHF. Because of the small, lightweight geometry of directional antennas at these frequencies, most RDF systems are physically-rotable throughout their 360 degree azimuth, using conventional antennas. By comparing the bearing co-ordinates of two or more directional antennas

at different locations, a high order of resolution is possible. The closer the bearing co-ordinates and baseline resemble an equilateral triangle, the closer the fix will be.

As with the lower frequencies, atmospheric skip, scatter, propagational refractions, and incidental reflections all contribute to inaccurate readings. For this reason, many readings over an extended period of time may be occasionally required for increased accuracy averaging out errors and discarding widely-divergent readings. Bearings taken near dawn or sunset are generally too unstable to be reliable.

An excellent broadband VHF direction finder is available from the "Happy Flyers",* a public service group composed of radio amateurs who are also pilots. Originally designed for finding downed aircraft, the RDF unit is a highly-effective add-on for either AM or FM receivers. Successfully used to locate intentional jamming, the unit boasts a pinpoint resolution of one foot at five thousand! (Fig. 5-16.)

*1811 Hillman Avenue, Belmont CA 94002.

COMMERCIAL ANTENNAS AND ACCESSORIES

Although many listeners enjoy designing their own antennas, many reputable manufacturers offer a wide selection of high-quality antennas fitting most any application and budget. Your local radio communications outlets should have an assortment of catalogs listing these products and their sources; information may be as near as your telephone.

References:

ARRL Antenna Book (ARRL, Newington, CN 06111) Reference Data for Radio Engineers (Howard W. Sams)

Chapter VI

Interference

Although the roaring distraction of a passing freight train is interference in every sense, we generally confine our definition of interference to include only those unwanted *electrical* intrusions which detract from the integrity of the desired signal. These may be divided into two main groups: incidental noise (random broadband pulses), and intentionally-generated signals (periodic or sinusoidal waveform).

Sources of interference may be natural or man-made, with the latter being locally the most severe most of the time.

Interference may be *conducted*, as over a power line or distribution system, or *radiated*, as by an antenna or stray, unshielded wiring. The method of entry into the receiver may be determined by disconnecting and reconnecting the antenna, listening for a change in the interference level; most interference will be brought in by the antenna.

City dwellers are the worst off, with average noise some 30 or more decibels above that detected out in the country; suburbs average between the two.

Natural noise may be *atmospheric*, caused by local or distant lightning, or *galactic*, from cosmic sources like the sun, Jupiter, and more distant objects. Whereas lightning discharges will propagate best at LF and VLF, galactic noise is limited by selective atmospheric absorption to the approximate range 18-500 MHz. Atmospheric noise ("sferics") and ionospheric disturbances both contribute communications-limiting characteristics.

Another form of natural interference includes static discharge, a result of gradual or erratic high-voltage leakage of static electricity from pointed conductors, or from humid, dirty insulation in the vicinity of the receiving antenna.

Similarly, electrolytic noises may result from corrosion; metallic surfaces rub together, generating minute erratic currents, resulting in noise. This condition is especially suspect in older installations and in coastal areas with air-borne salt.

Man-made noise. Spark-generated pulse noise is the worst offender in the kingdom of noise; it peaks in the

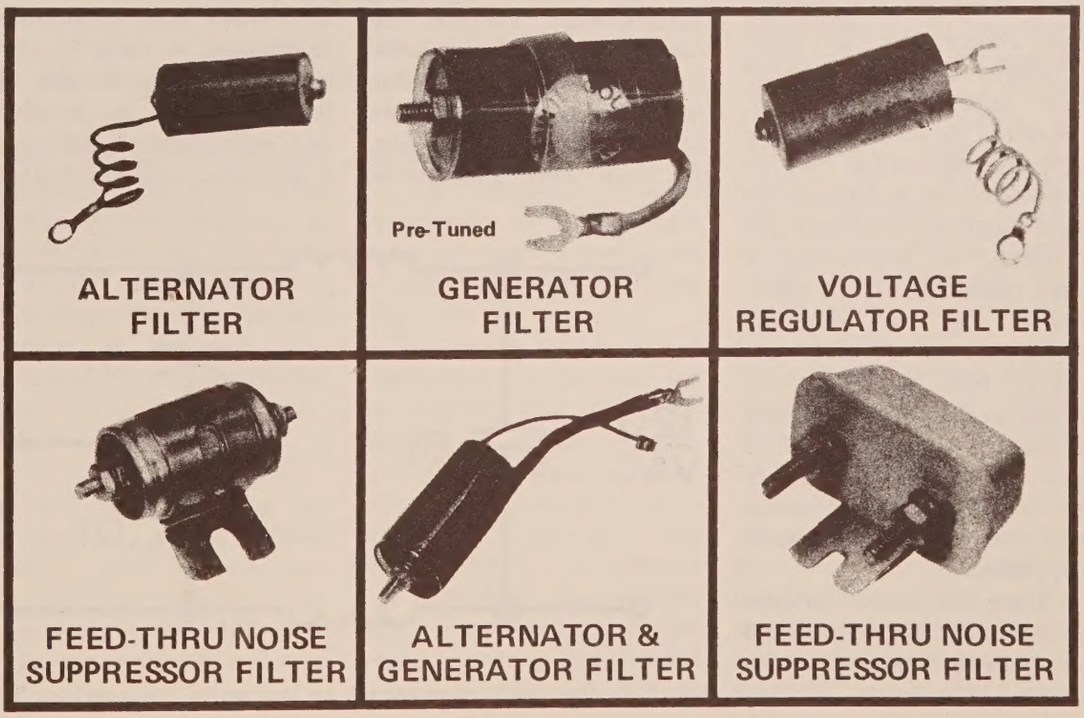


Fig. 6-1. A wide array of filters is available on today's electronic marketplace to satisfy most conducted noise. (Courtesy Gold Line.)

VLF range, gradually rolling off well into UHF. Unlike most natural noise, spark noise from a manufactured device may be suppressed at its source (Fig. 6-1). Additionally, a well-grounded, brute-force, low pass line filter at the receiver is recommended to limit random line noises.

Any defective power-distribution lines or related equipment should be reported to the electric utility company servicing the area; they are in violation of Part 15 of the FCC Rules and Regulations (incidental radiation). If the company fails to respond, notify either the public utilities commission or your district FCC office.

A transistor radio is generally an effective probe for tracking down noise interference. While monitoring the noise on a vacant setting of the radio dial, switch your house circuit breakers on and off, listening for an abrupt stop or attenuation in the noise level. Once the circuit is found, it is a simple matter to locate the offending device by unplugging or switching connected equipment.

Assuming that the noise is *not* generated on your property, a search of the neighborhood is in order. Naturally, the cooperation of your neighbors must be elicited for this approach. Their cooperation in correcting their defective equipment may be expected both as a matter of safety and law; your help will probably be appreciated if they request it. If it is determined that the offending equipment is operating normally, then filtering techniques as described below will probably be necessary, unless you can convince the owner to acquire newer electrical equipment with internal noise suppression!

There are several varieties of man-made interference and recommended procedures for their attenuation. *Brush/commutator motors.* Appliances such as sweepers; carving knives; sewing machines; mixers and blenders; hair dryers and clippers; fans; disposals; toothbrushes; floor polishers; and carpet shampooers, power tools such as drills; lathes; saws; grinders; sanders; lawn edgers; and hedge trimmers, toys such as battery-operated and transformer-operated trains, and industrial machines such as cash registers; tape calculators; teleprinters; and facsimile machines.

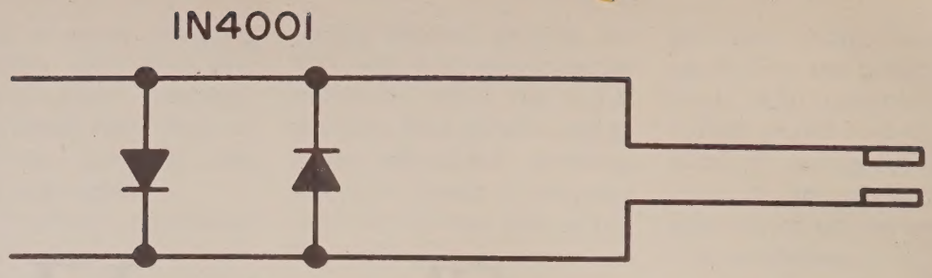


Fig. 6-2. Cross-Polarized diodes may be effective in reducing low voltage contact arcing.

Fortunately, most larger motors (pumps, elevators, subway and trolley cars, clothes washers and dryers, furnace and air-conditioner blowers, dishwashers, refrigerator and freezer compressors) use brushless induction motors and generate noise only if extremely dirty. Many use inertia-start switching and will briefly generate brush noise.

Remedies. The offending commutator should be cleaned, or turned on a lathe if visibly worn. Large-value (up to 2 mfd) capacitors are placed on the motor housing, and both filter and motor housing must be well-grounded.

In the case of portable equipment motors, capacitance is limited to prevent shock hazard, usually to .005-.01 mfd. Three-wire grounded lines have an advantage in this respect as they will accomodate higher bypass capacitances without increasing shock hazard.

Mylar capacitors are generally adequate for most applications, with voltage rating of 600 or 1000 to withstand transients. For more stubborn cases, coaxial feedthrough capacitors are a better choice, as they extend the range of noise suppression to at least 150 MHz.

Occasionally the only remedy that will work is the brute-force line filter, a low-pass inductance-capacitance combination with a proven history of performance. As with other noise-suppression techniques, it must be connected as close to the offending device as possible, and well-grounded. Additional grounded shielding as a last resort is sometimes necessary.

Contact switching. These devices include power switches, vibrating-contact tools, fence chargers, appliances, power supplies, relays, animated signs and displays, voltage regulators, traffic signals, and thermostats (furnace and air conditioner, fish aquarium, oven, iron, electric blanket, bottle warmer).

Remedies. In many cases a suitable-wattage current-limiting 47 to 100 Ohm resistance in series with the contacts will help, provided the additional resistance will not degrade the performance of the device. A parallel resistance of 5 to 22 megohms will sometimes help. In more stubborn cases, a 10 to 100 Ohm resistor in series with a .01 to .5 mfd capacitor may be placed across the contacts to suppress spark noise; experiment to determine the best combination.

An alternative transient suppressor may be made by connecting two silicon rec-

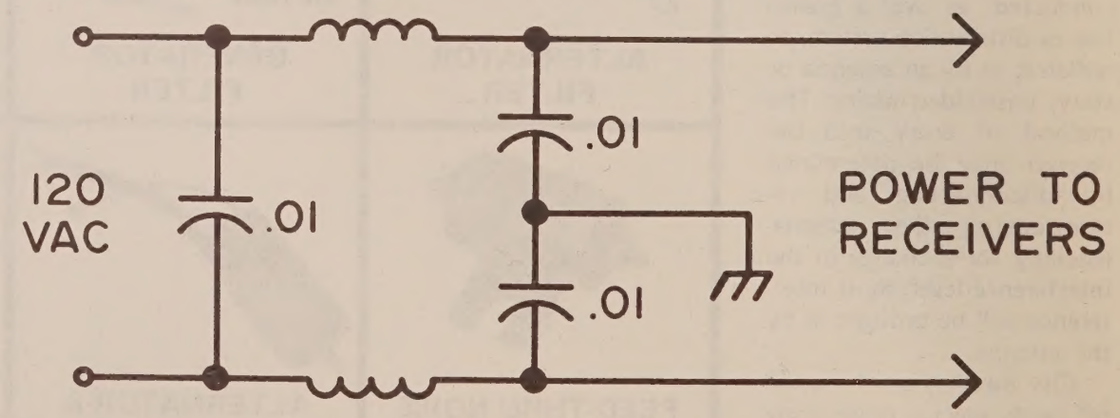


Fig. 6-3. The classical approach to line noise attenuation: The brute force filter. Both coils are wound in opposite directions on a ½" wooden dowel (or heat-resistant plastic rod). Each coil consists of 28 turns of #14 enameled wire spaced to a length of 3½". A shielded grounded box will also help.

tifiers back-to-back across the contacts (Fig. 6-2).

Power-line conducted noise. This can come from such items as defective "pole pig" line distribution transformers; worn, cracked, or dirty insulators permitting high-voltage leakage or precipitation static (most severe below 10 MHz); loose wiring or ground leads; old street lamps.

Remedies. Once located or suspected, notify the power company as recommended earlier; no individual is permitted to work on utility equipment unless employed by the power company.

At the receiving position, experiment by reversing line plugs, connecting and disconnecting ground straps to reduce conducted line noise. A good line filter is recommended at any installation (Fig. 6-3).

Ionization interference. This can be caused by fluorescent lamps, neon signs, high-voltage corona discharge, and medical equipment.

Remedies. Because of the broad-spectrum conducted and radiated nature of these sources of radio interference, special techniques are generally required to attenuate their spurious emanations. For fluorescent and neon lights, all metal parts should be bonded with wire braid and grounded. Open areas, including the lamp aperture itself, may require screening.

While bypass capacitors might be enough, RF chokes may be required, and high-voltage filters may be required for neon-sign hash suppression (Fig. 6-4).

Most medical equipment now in operation and being manufactured are under rigid specifications. Interfering equipment is usually defective or improperly adjusted, rather than inadequately designed.

High-voltage corona discharge normally appears near pointed conductors in high-tension circuitry. In TV sets, this is associated with the high-voltage circuit, most of which is in a shielded box. If a blue haze can be seen surrounding a lead or component in the high-voltage section, it may be painted or sprayed with anti-corona dope made specially for that purpose. A thorough dust cleaning is recommended which sometimes solves the problem.

Ignition noise. Caused by automobiles, trucks, buses, tractors, lawn mowers, furnace ignitors, and boats. This noise peaks in the 40-50 MHz range, and continues well into UHF.

Remedies. Although interference to a monitoring installation is common from nearby vehicles, satisfactory listening in a mobile installation is seriously debilitated by the proximity of electrically-noisy vehicles (including its own!). The two prime offenders are the spark-ignition and battery-charging systems.

Bypass capacitors must exhibit a very low RF impedance compared with the circuit load impedance to be effective; in actual practice, .1 mfd is adequate for frequencies above 2 MHz in all applications. Coaxial feedthrough capacitors are more effective above 3 MHz than other types; an additional .005 mfd capacitor for VHF attenuation should be connected across the coaxial capacitor. Short leads are mandatory.

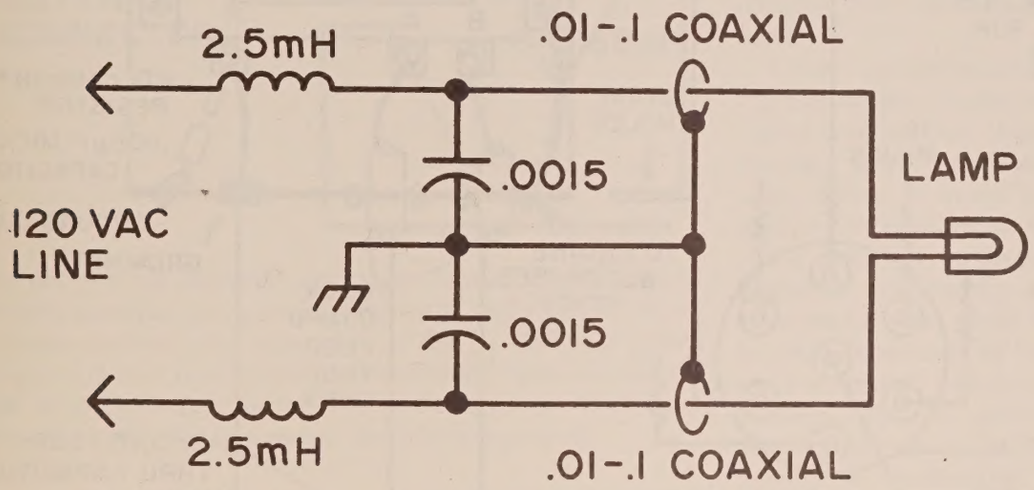


Fig. 6-4. Fluorescent lamp noise filter.

The following noise-suppression steps are listed in order of likely effectiveness in reducing automotive noise (Fig. 6-5):

Spark plugs. This source of interference is characterized by popping shot noise, increasing in frequency with acceleration. Resistor plugs are recommended over attachable suppressors, and are available in both shielded and unshielded construction; they *do not* degrade engine performance! High-quality resistance ignition leads are recommended; or, use a wire-conductor cable and solder the terminals at the ends. Check the distributor as well for center-wire continuity and proper rotor gap.

Alternator or generator. This source of interference is characterized by a whine which increases in pitch with acceleration. A .1 or .5 mfd capacitor should bypass the alternator output or generator armature. For more severe cases, a series wavetrap is required on that lead; for the 25-50 MHz range, use 8 turns of #10 wire on a 1-inch diameter form, paralleled with a 3-35 pf compression padder capacitor, and adjust for maximum attenuation at the desired monitoring frequency. Commercial wavetraps are available from CB radio stores for this same purpose.

Voltage regulator. Bypass the battery lead terminal with a .1 mfd capacitor (the armature is already bypassed by the preceding step). Install a 4 Ohm (3.9 Ohm) 1-Watt carbon composition resistor in series with a .005 mfd capacitor from the field terminal to ground.

Coil. Connect a .1 mfd capacitor from the battery lead (*not distributor lead*) to ground.

Body bonding. Long, conductive extensions are ideal noise-transmitting antennas; their floating extremities should be bonded to the car frame by short lengths of tinned-copper braid. Use the lighter braid to ground cables (choke, temperature, control cables) to the firewall at their points of feedthrough. Use heavy braid to bond the exhaust pipe, muffler, steering column, engine block, firewall, air cleaner, hood, bumpers, tailpipe, and trunk lid to the car frame.

Instruments and accessories. Long wire runs are potential noise-radiators; bypass with .1 mfd coaxial capacitors *at the device* the following typical battery or hot-lead runs: Instrument cluster gauges, ignition switch, lights, radio, tape deck, and accessories. Additionally, .1 to .5 mfd

capacitors should be attached to the hot leads of turn signals, window motors, heater fan, electric windshield wipers, and heat and fuel-level senders.

Frictional static. Wheel noise may be eliminated by the installation of special spring-loaded static collectors inside the bearing caps; tire noise is eliminated through the injection of graphite powder. Belt static may be reduced by the installation of grounding brushes against the pulleys.

Normally, the first two or three steps (plugs, alternator, regulator) will be all that are necessary to bring vehicular noise down to an acceptable level. It is worth repeating that .1 mfd coaxial feed-through capacitors are recommended for bypass applications, although more expensive EMI-RFI feed-through filters are available with wide-band noise suppression characteristics.

Conventional bypass capacitors (mylar) are acceptable for moderate noise levels, but are not satisfactory in all applications. They are certainly worth trying before resorting to more expensive noise-reduction components.

In all cases of interference, automotive and otherwise, always try the least expensive and easiest cure first.

NOISE INTERFERENCE AT THE RECEIVER

It is certainly outside the realm of reason to assume that all causes of electrical interference will be suppressed at their sources; therefore, certain considerations must be taken at the receiver. A good receiver will have an effective noise limiter; it must be capable of preventing random pulse noise from entering the audio

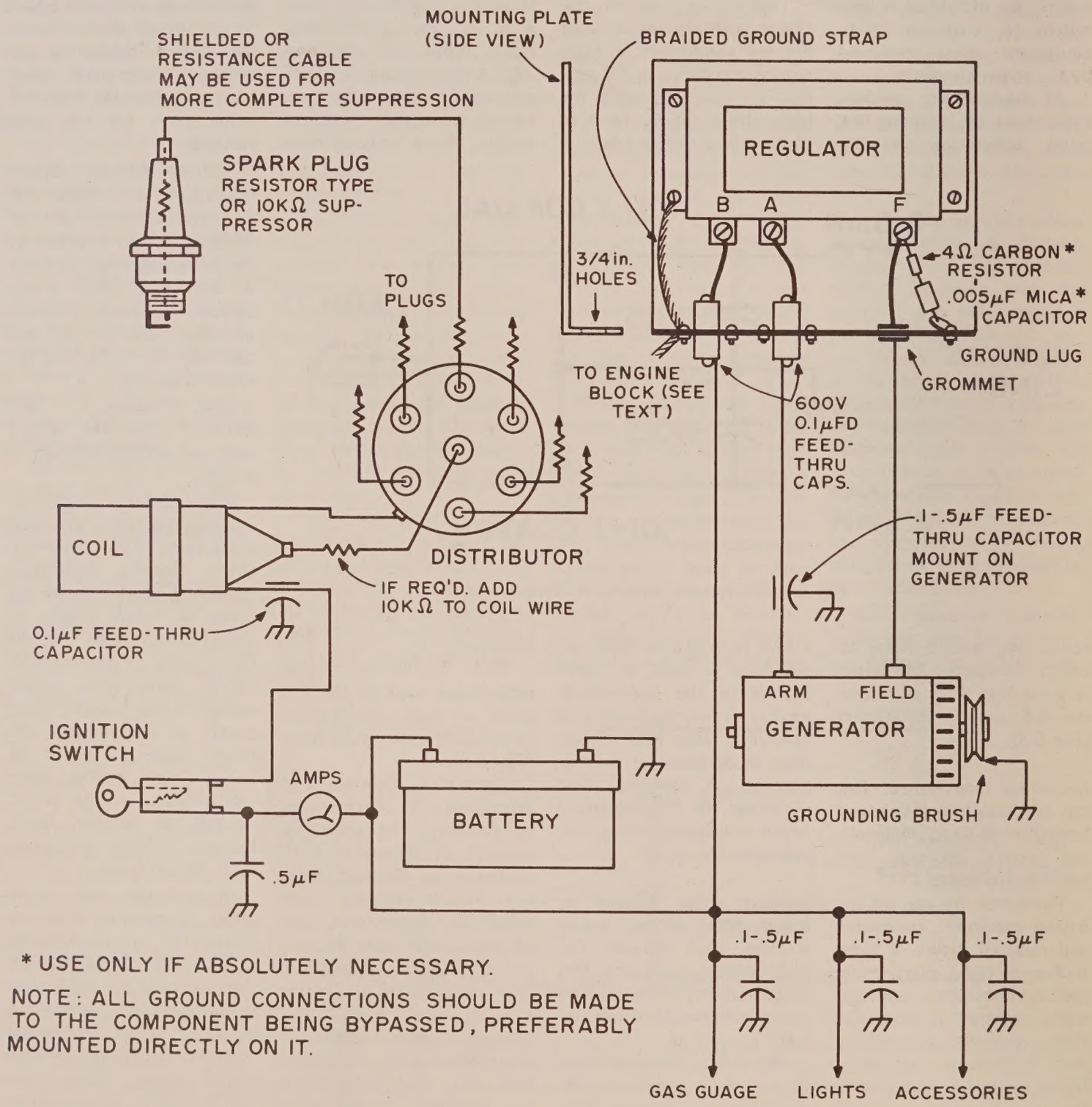


Fig. 6-5. Several suppressive steps must sometimes be taken to reduce automotive noise.

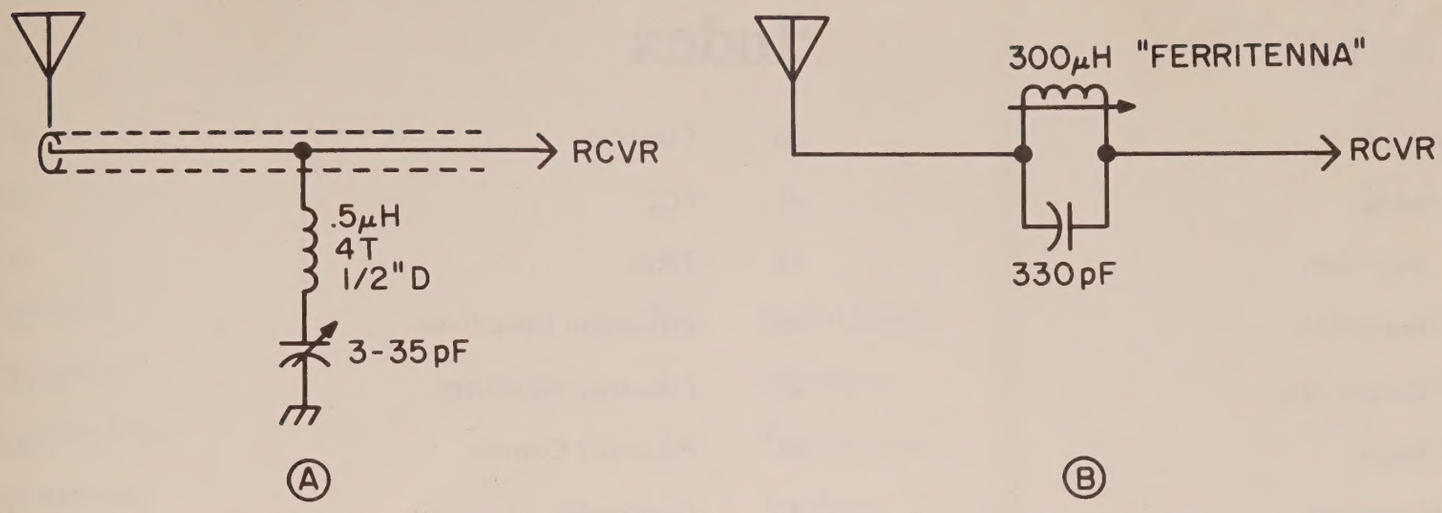


Fig. 6-6. Simple effective wavetraps to reduce interference are shown. (A) is for 50-220 MHz signal interference while (B) is for AM broadcast interference. Both should be mounted in shielded enclosures and use short leads or shielded cable.

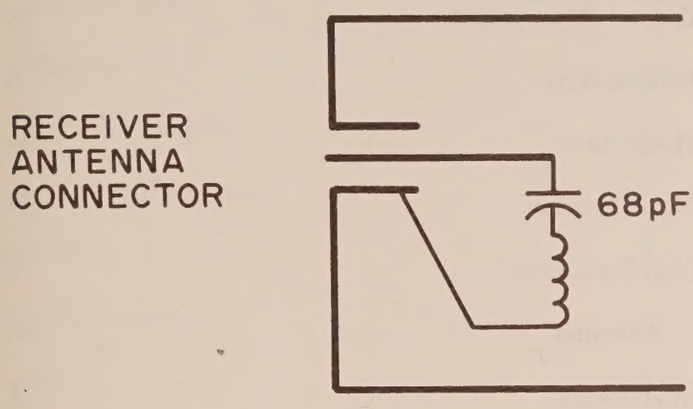


Fig. 6-7. An FM broadcast wavetrap is shown. The 68 pF disc ceramic capacitor has one lead cut short and soldered to the antenna terminal, the other lead is cut to 1½" then coiled around a ½ Watt resistor body. The resistor is removed and the lead is soldered to ground. The coil's turns are then compressed or stretched to suppress the interfering signal.

output, while maintaining the integrity of the desired signal with minimum distortion.

Additional anti-noise measures at the receiver include braid-bonding all equipment commonly, and grounding well.

Coaxial down-lead is recommended for all antenna transmission lines, with good ground connections.

The antenna itself should be situated away from house wiring, and should not parallel nearby power lines.

INTERFERENCE FROM INTENTIONALLY GENERATED SIGNALS

The impact of radio has spawned an enormous number of devices which generate radio signals throughout the spectrum, causing interference other than broadband pulse noise. Their spurious emissions must be attenuated by law, but that fact does not necessarily make it so. The spectrum is resplendent with splatter, keyclicks, IF and oscillator radiation from TV and FM radio sets, TV sweep buzz, diathermy and industrial induction heating signals, electronic calculator clock-circuit radiation, and radiation from RF test equipment.

Even properly-allocated transmissions contribute signal-covering or heterodyning; local broadcasters cause receiver front-end overload and its resulting desensitizing and intermodulation. **Remedies.** Fortunately, there are remedial steps which may be taken in virtually all forms of transmitted interference. In many cases, the answer is simply better grounding techniques, or re-directing the antenna, or changing its polarization. If the source of keyclicks or overmodulation splatter can be identified, the offending station and/or the FCC should be notified, giving as detailed a description as possible.

High-selectivity receiver circuitry will certainly reduce heterodyning from interfering signals, as will changing antenna direction. Unfortunately, diathermy and induction heating signals may be propagated thousands of miles, and locating them is often extremely difficult. FCC notification might initiate their cooperation in direction finding.

The problems caused by nearby properly-functioning transmitters are generally simple to cure at the receiver: good common grounding, directional antennas, or the installation of a simple wavetrap in the receiver antenna line (Fig. 6-6). A pair of cross-polarized silicon or germanium diodes connected across the receiver antenna input will limit large RF voltages.

The troublesome radiations from TV horizontal-sweep circuits, and radio and TV IF radiation, must be suppressed at their sources. Simple wavetraps or bandpass filters are virtually always effective.

In the case of digital-calculator clock-circuit noise, shut it off!

As a last resort, the listener still has three more options: modify his listening schedule to accomodate the noise generators, take up a new hobby, or move out to the country!

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Epilogue

It is hoped that this book has provided some useful guidelines toward the successful implementation of a communications monitoring installation. Comments are welcomed by the author.

The world of communications is enormous, and will continue to grow explosively. As transmitting technology becomes more sophisticated, receiving technology must keep pace.

"Speech is civilization itself. The word, even the most contradictory word, preserves contact . . . it is silence which isolates".
Thomas Mann

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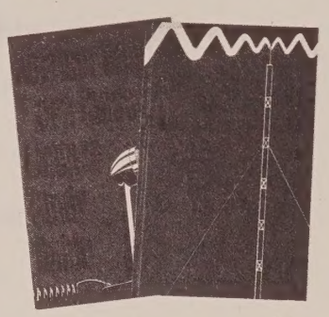

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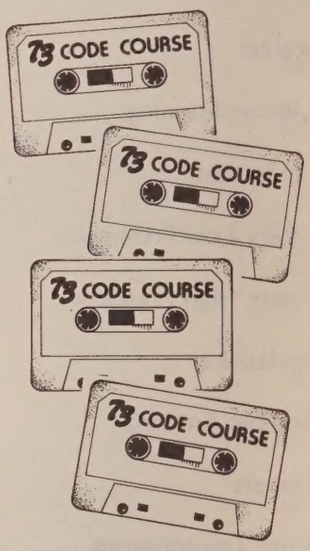

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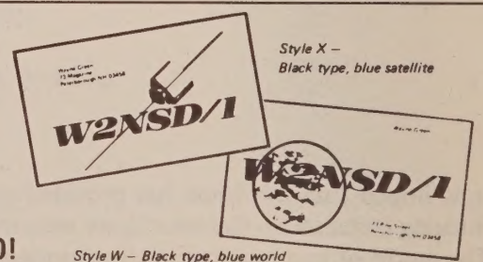

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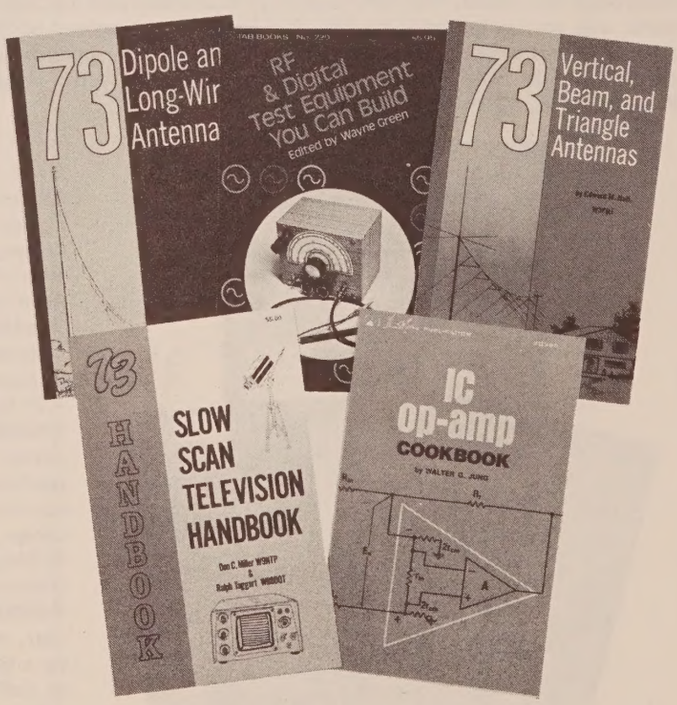
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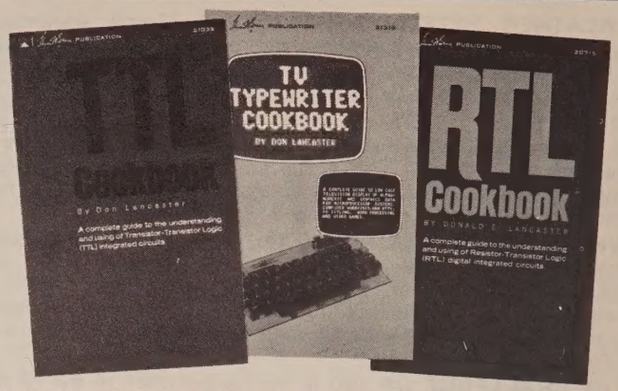

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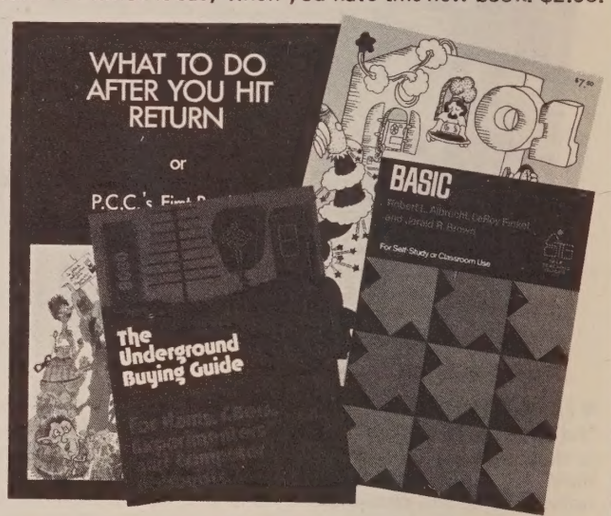

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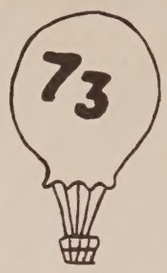

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About the Author

Bob Grove became interested in radio communications at an early age. A licensed amateur by the age of 13, he pursued his scientific interests and received his bachelor of science degree from Kent State University. After moving to Florida, Grove continued his academic training and finished his graduate studies at Florida Atlantic University, from which he received a masters degree.

He has an interesting and diverse professional background being Director of two Science museums and planetariums, an award-winning television public-affairs director, and a science teacher. He is currently Science Chairman in the Broward County public schools in Florida.

An accomplished author, Bob has an international reputation as an expert on the communications field primarily as a result of the success of his previous book, *Confidential Frequency List* (Gilfer Associates, 1976).